TECHNICAL REPORT 180

A PROGRAM FOR THE DESIGN OF PROCUREMENT SYSTEMS

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May 1976

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LABORATORY FOR COMPUTER SCIENCE
(formerly PROJECT MAC)

CAMBRIDGE MASSACHUSETTS 02139

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by

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Submitted to the Department of Electrical Engineering and Computer Science on May 7, 1976 in partial fulfillment of the requirements for the Degree of Master of Science.

ABSTRACT

Computer technology has had limited success in producing useful business applications. Management systems seldom meet users' requirements, are often inappropriate to an application, and are frequently abandoned. But why?

Business lacks expertise in the application of computers. Managers who are expert in solving business problems find it difficult to specify formal procedures for the solution of these problems. It is not surprising that programmers who work from poorly defined specifications produce poorly written software. The computer industry has provided only limited support in business applications. Application packages are seldom appropriate to a problem and are often misapplied. Misapplication is the principle reason for their failure in practical situations.

Improvements are certainly possible. The manager could be supplied with a system that assists in the design of an application. This system could help the manager specify his requirements by providing him with a framework for thinking about issues relevant to the design of a particular application. The manager might then be better equipped to select a commercial package or to guide in the design of his own implementation.

This thesis describes a prototype version of such a system. PROCTOR is a program that assists in the design of a hierarchical planning and control system for a procurement firm.

PROCTOR is implemented as an "unstructured" questionnaire. It guides the user in investigating various aspects of a problem while giving him complete freedom in deciding how and when to supply answers to questions. It allows him to change and skip answers whenever he desires. PROCTOR is implemented in OWL, a system for representing and processing conceptual knowledge. It uses the OWL data base to represent procedures for the questionnaire and to store data accumulated during the interaction. This representation makes possible the presentation of an English-like problem description, various evaluations and the reasons for the evaluations.

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ACKNOWLEDGEMENTS

I would like to express my thanks to all of the people who aided and encouraged this work: to Professor Bill Martin who suggested Operations Management as a research area and who encouraged this research; to Professor Arnoldo Hax who provided the questionnaire on which this thesis is based; to the OWL group for the design of the OWL system, and especially to Lowell Hawkinson who implemented the OWL data base system; and finally, to the members of the COMS group and the Automatic Programming Group for their suggestions and for providing a congenial working environment.

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Office of Naval Research under Contract Number N00014-75-C-0661.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Introduction

Computer technology has had limited success in producing useful business applications. Management systems seldom meet the users' requirements, are often inappropriate to an application, and are frequently abandoned. But why?

Business lacks expertise in the application of computers. Managers who are expert in business problems find it difficult to specify formal procedures for the solution of these problems. It is not surprising that programmers who work from poorly defined specifications produce poorly written application software.

The computer industry has provided only limited support in business applications. Application packages should theoretically provide instant data processing software. In practise, they require considerable modification to be compatible with a firm's procedures. Application customizers are proposed as a solution to this problem. These systems tailor application packages from user specifications. Unfortunately, outputs from application customizers still require modification to fit the environment of a firm.

Application customizers (and application packages) have a more serious limitation: a user is rarely provided with evaluations concerning the suitability of a package for his firm. A company will invest considerable time and expense in "ready to run" software only to discover that it is inapplicable to its problem. And worse, the unsuitable package can sometimes aggrevate a company's problems.

Improvements are certainly possible. The manager could be supplied with a

system that assists in the design of an application. This system could help the manager specify his requirements by providing him with a framework for thinking about issues relevant to the design of a particular application. The manager might then be better equipped to select a commercial package or to guide in the design of his own implementation.

This thesis describes a prototype version of such a system. PROCTOR is a program that guides the user in the design of a system for a particular application. The application is assumed to be a planning and control system for a procurement firm designed according to the aggregation methodology of hierarchical planning and control described by Hax and Meal. <Hax and Meal 75>

PROCTOR is based on a questionnaire written by Professor Arnoldo C. Hax. This questionnaire served as a summary of issues to be considered in the design of a hierarchical planning and control system for procurement. The questionnaire served as a basis for an analysis that in turn influenced the implementation of PROCTOR.

PROCTOR is implemented as a "unstructured" multiple choice questionnaire. It guides the user in investigating a problem while giving him complete freedom in deciding how and when to supply answers to questions. PROCTOR allows the user to change and skip answers whenever he desires.

We have implemented PROCTOR in OWL, a system for representing and processing conceptual knowledge. <Hawkinson 75> PROCTOR uses the OWL data base to represent the procedures for the questionnaire and to store data accumulated during the interaction. The data base makes possible the presentation of an English-like summary of the problem setting as well as recommendations concerning a possible system for the problem.

1.2 Background

1.2.1 Application Customizers

In the introduction, we mentioned that users of application customizers frequently encounter problems. IBM's Application Customizer <IBM 72> and the Distributions System Simulator <Connors 72> are typical examples of application customizers.

The Application Customizer is a system that uses a questionnaire to derive a set of parameters that are subsequently used to customize data processing software. The most serious limitation of the Application Customizer is that it does little in terms of problem formulation. <Hax and Martin 73> The Application Customizer cannot evaluate the applicability of its output for a particular situation. In using the Application Customizer, the user bears full responsibility for identifying his processing requirements and for determining if the resulting system is indeed appropriate to his problem.

The Distribution Systems Simulator (DSS) is a system that uses a questionnaire to customize a simulation model for large scale physical distribution systems. DSS offers an improvement over the Application Customizer by providing a means of evaluating distribution systems methodology. But it also is inadequate <Hax 74b>. DSS does not take a global view of the firm in its evaluations. It ignores important issues such as the interaction of the firm's production activities with the distribution process: it treats manufacturing plants as sources of unlimited inventory. DSS does not provide an integrated approach to the logistics process: it treats each stocking point as if it were independent from the rest of the system.

1.2.2 Requirements for an Improved System

The minimum requirements for an improved system should be clear. A system that is to provide an improvement over existing systems should assist the user in (1) identifying his requirements, (2) selecting components to meet his requirements, and in (3) evaluating the suitability of these components for his situation. In meeting these objectives, the system must take a global view of the firm.

PROCTOR tries to meet these objectives by means of an interactive multiple choice questionnaire. We chose this approach for several reasons. It has proven successful in both the Application Customizer and the Distributions System Simulator and seemed to be the simplest technology which could support an advance over existing systems. A questionnaire requires a minimum of input and is therefore readily accepted by management. A questionnaire provides a framework in which it is possible to educate a user: it can guide the non-expert in the description of his problem.

We have made several improvements in the presentation of the questionnaire. It is often the case that the user cannot continue in a questionnaire because he does not know an answer or because he does not know how to answer a question. Many systems are unable to proceed unless an answer is supplied. (It is poor software engineering to force the user to leave a long involved interaction in order to determine a single piece of information.) PROCTOR allows the user to skip a question whenever he desires. It then tries to determine the fact by using information that it already knows or by using a different strategy in asking for information. PROCTOR can also proceed to another part of the investigation. The user can interrupt PROCTOR at any time to supply answers to questions that have been skipped.

Associated with the ability to skip answers is the ability to change answers whenever the user desires. The user may wish to change a previous answer: the program may have detected the inconsistency of a response with previous information; the user's supervisor may disagree with information that has supplied. PROCTOR is able to change answers without having to restart the investigation.

A deficiency with application customizers is their inability to provide evaluations before the completion of the questionnaire. The Application Customizer questionnaire must be completed before any output is available. PROCTOR can provide partial evaluations before a session is completed.

1.2.3 Methodology for Research

1.2.3.1 A Consultant's Questionnaire as Protocol

PROCTOR is based on a questionnaire written by Professor Arnoldo C. Hax. Professor Hax has discussed the need for programs capable of automating the design of logistics systems <Hax 74c>. As an attempt towards such a system, he wrote in a questionnaire format his strategy for tackling procurement problems.

The questionnaire served as a summary of issues that had to be considered when attempting the design of a hierarchical planning and control system for procurement. An analysis of the questionnaire lead to a theory of its structure that in turn influenced the implementation of PROCTOR. This will be discussed in a later chapter. It suffices to note that several assumptions had to be made in the writing of the questionnaire and its subsequent analysis.

1.2.3.2 Some Necessary Assumptions

The questionnaire only considers operational and tactical issues. It contains no questions concerning long term strategic considerations such as those involved in the design of plants and warehouses or the allocation of capital. Although this is a reasonable restriction, it can lead to complications. The consultant is often confronted by a situation that on the surface seems to be a procurement problem. On further investigation, the real problem is often found to be quite different: the firm's facilities could be constrained and require expansion; funds for inventory investment might not be available due to limited cash flows that arise because of the firm's credit policy.

We assume that before using the program, the user will have analyzed his situation to the extent that he is convinced that a purchasing or inventory problem requiring a procurement system exists. Thus, the questionnaire tackles only operational and tactical issues without regard to strategic, long term issues that are assumed to be externally constrained.

Another problem is the evaluation of the numerous intangibles involved in deciding whether or not to use a particular logistics system. It is inconceivable given the current state of the art that a program be able to decide in <u>any</u> situation whether a planning and control system should be adopted. For a general analysis, a program would require a set of well-developed world models to enable it to relate to the many secondary issues involved. A manager is needed to evaluate intangibles such as organizational issues and financial considerations related to an overall decision.

1.3 Operations Management Issues

In this section, we outline the kinds of procurement problems that PROCTOR considers. We also describe the hierarchical approach to planning and control systems described by Hax and Meal.

1.3.1 The Procurement Problem Outlined

Procurement refers to the ongoing activity that all firms have of purchasing materials and supplies from outside sources. A manufacturing firm will purchase raw materials to supply its production process. For a distributor (such as a supermarket chain), procurement depends on the requirements of the individual stocking points. Many firms (retailers and wholesalers, for example) purchase goods simply to satisfy the demands of their customers.

In this thesis, we consider those firms whose major activity is procurement. In this class, we include not only simple retailers but also firms that have minor production activities with negligible production lead times (such as packagers) and firms which have distribution activities that can be assumed to be independent of the procurement process.

Support for the procurement process depends on the time horizon in which we hope to provide support. For a horizon of more than a year, long-term issues such as the acquisition of plant and equipment assets and facilities design become important. Product line selection may also be considered. For a very short horizon of a few days to less than a month, issues related to the detailed scheduling of company operations become important. For a medium horizon of less than a month to a year, we become concerned with the forecasting of customer demand, the planning of inventory levels and the purchasing of

goods. This thesis considers issues of planning and control in the medium time horizon.

Within this time horizon, the firm's objective is to provide good customer service at minimal cost without violating constraints that are imposed either externally or internally to the company. Unfortunately, a firm can meet many problems in trying to meet this objective.

A company that cannot adequately forecast customer demand will suffer a deterioration of customer service and subsequent loss of business. In addition, it will often accumulate excess inventory. This merely aggrevates the situation by wasting valuable space that should be used to hold goods that are currently in demand.

A firm that is unable to predict the lead time between the issue and receipt of an order from a vendor will usually suffer missed customer orders and lost sales. To solve this problem, a company will sometimes issue many small orders. The result is excessive ordering costs.

A firm's procurement problems can sometimes result from its inability to operate within the constraints imposed on it. Vendors occasionally set supply limits and sometimes require constant purchasing rates. Occasionally, the finance department of the firm can impose a constraint by limiting funds available for investment in inventory.

All these problems warrant the consideration of a planning and control system. But a firm need not have procurement problems to consider such a system. Indeed, a firm may consider a system simply to maintain its competitive advantage. With a planning and control system, a firm will be better able to predict customer demand to take advantage of discounts and economies of transportation when ordering from vendors. Extra cash is made available to finance other aspects of the company's operations by keeping inventory

investment at a minimum.

1.3.2 The Hierarchical Approach to Planning and Control Systems

There are several approaches to the design of a planning and control system for the procurement situation. One proposal is to formulate the control problem as a single mixed-integer programming problem (MIP) to be solved on a rolling horizon basis. <Lasdon and Terjung 71>

Several researchers have discussed the deficiencies of this approach. (See, for example, <Bitran and Hax 76>.) One problem with the detailed approach is that it requires data such as forecasted demand for each item over the planning horizon (usually a year). For several thousands of items, not only do data requirements become overwhelming but usually it becomes computationally impossible to obtain a solution to the MIP. Another objection to the detailed solution is that it provides no means for management intervention in the solution process.

Hax and Meal and others (see <Hax and Meal 75> and <Hanssman and Hess 60>) have recommended a hierarchical approach to planning and control. In this thesis, we assume the approach of Hax and Meal as the proposed methodology for a planning and control system.

The hierarchical approach requires that aggregate decisions be made first, and that these be later used to constrain more detailed decisions. Each level of decision making has its characteristic length of planning horizon and data requirements. More aggregate decisions involve longer horizons and less detailed kinds of information. With the hierarchical approach, the manager is able to influence the solution at each level of decision

making. Typically, upper management will influence the decisions at a higher level of aggregation.

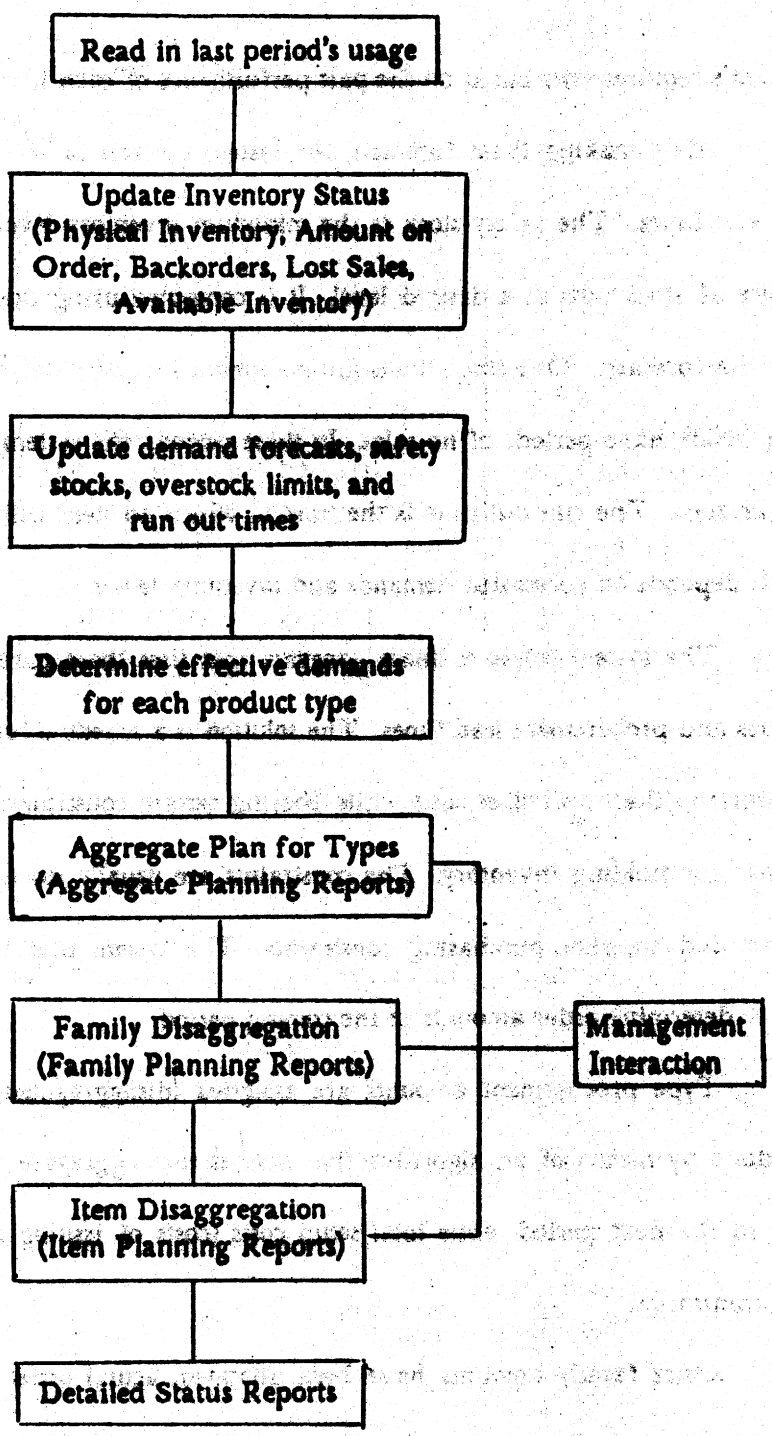
In designing a planning and control system, the types of aggregations required, the problems to be solved at each level of aggregation and the linkage mechanism between levels must be selected.

For medium range planning problems (a horizon of approximately a year), three levels of aggregation have been identified:

> *Items* are final products to be delivered to the customers. They represent the highest degree of specificity regarding the products handled by the firm. Items differ in terms of characteristics such as color, packaging, labels, accessories and size.
>
> *Families* are groups of items which share a common ordering cost. Economies of scale are made possible by jointly replenishing items belonging to the same family.
>
> *Types* are groups of families whose procurement quantities are to be determined by an aggregate plan (a linear programming model at the type level). Families belonging to a type normally have similar inventory characteristics and similar demand patterns.

These three levels of aggregation are used in COMS, a Computer Based Operations Management System. <Hax, Golovin, Bosyj and Victor 76> This system was designed as a research tool to explore various techniques for linking between the levels of aggregation. COMS has strongly influenced our model of a general hierarchical planning and control system. Figure 1.1 gives a conceptual overview of COMS.

After updating last period's performance statistics, demands are forecast both at the type and the item level. The type level forecast is made over the planning horizon (usually a year). The system aggregates data to the type level to minimize errors due to the uncertainty of future requirements at the item level. It is thus able to provide a more realistic forecast over the planning horizon. The item level forecast is simply a forecast of



Conceptual Overview of a Hierarchical Planning System

Figure 1.1

next period's requirements based on the past performance of each item.

After making these forecasts, the system updates safety stocks, overstock limits and run out times. The safety stock is the minimum inventory level necessary to keep the probability of stock outs at a desired level. It is computed using the standard deviation of errors in the forecasts. Overstock limits are maximum inventory levels. They are important for items which have periods of no sales. In these periods, the system tries to keep inventory levels near zero. The run out time is the time in which an item will run out if no order is placed. It depends on forecasted demands and inventory levels.

The system solves a linear program that uses these parameters as well as type inventories and procurement lead times. The solution is a schedule for procurement over the coming horizon that minimizes costs while obeying certain constraints. The most important cost is that for holding inventory. The constraints are usually storage constraints, seasonal constraints and supplier purchasing constraints. The system uses the first period in the solution to determine order amounts in the coming period.

Type procurement amounts are assigned (disaggregated) to families in types. This is done by means of an algorithm that insures that aggregate demand for families is satisfied in the next period while total setup costs (costs of issuing an order) and holding costs are minimized.

Once family amounts have been allocated, actual order amounts for items in families are assigned. To reap benefits of joint economies of scale, items in a family should be ordered together. Item amounts are allocated so that family members run out simultaneously.

The preceding description is that of a fairly general planning and control

system. In certain cases, only some of the components are applicable. The aggregate planning component may be eliminated when a firm has no long-term external constraints. Families are not present when items can only be ordered individually from vendors.

The aggregation approach has been tested for several problems using the COMS system. <Hax et al. 76> It is interesting to note that costs obtained using this approach are very near the lower bound costs provided by the MIP formulation. In some cases, COMS has been able to provide a feasible solution while the MIP has failed due to computer storage limitations.

1.4 Preview

In the next chapter we present a sample session using PROCTOR. Chapter 3 contains a description of the questionnaire. In chapter 4, we develop a model of the questionnaire strategy. Chapter 5 describes the implementation of this model.

CHAPTER 2

A SYSTEM DEMONSTRATION

Chapter I introduced the procurement problem and the hierarchical approach to its solution. It also presented a set of requirements for a system to assist the manager in evaluating the suitability of that approach for his firm. In this chapter, we describe a session with the current implementation of the system. We will demonstrate PROCTOR by outlining the experiences of a typical user.

2.1 Introduction

Adam Smith is manager of operations at KBS Foods Limited, a noted wholesaler of specialty products. KBS purchases prepackaged foods, occasionally repackages them and sells them to gourmet shops and direct to the public. For KBS, repackaging is a minor activity that requires no lead time and little overhead: it simply involves relabelling items for certain shops. KBS Foods handles more than 5000 items. Demand for these items varies according to the season with peaks at holiday times.

KBS is currently experiencing problems in its inventory management. Items are often understocked; an item is occasionally unavailable due to monthly supply limits imposed by vendors; orders are often missed or shipped late. KBS has also overstocked some of its items. This has created a significant overhead in operating expenses since items that cannot be sold incur storage costs or have to be liquidated.

Mr. Smith believes that computer control of the procurement operations of KBS Foods would be the most appropriate solution. He is especially interested in an

approach that uses management science techniques. An associate has suggested that he use PROCTOR to help him decide.

2.2 The Session

In the following pages, we present segments of Mr. Smith's session with PROCTOR. The complete session appears in Appendix A.

****

Mr. Smith has just completed investigations into support for joint ordering interactions. PROCTOR has concluded that joint ordering support is feasible because KBS Foods has a significant number of items that share ordering costs and because these items can be grouped into families for purposes of joint replenishment. PROCTOR now begins investigations into external constraints.

And Mr. Smith, we will now attempt to identify whether there are external constraints among your items that warrant the development of an aggregate plan and the aggregation of items and families of items into product types. Do you need further information with regards to external interactions?
(Please key in yes or no): yes

The presence of external constraints such as storage limitations, financial constraints, limited capacity of individual vendors, and need to smooth purchasing orders under fluctuating requirements may force the development of a purchasing plan during a long time horizon (usually a year). Items and families of items are then aggregated into product types to facilitate the design and implementation of the plan. An aggregate purchasing plan is required whenever purchasing decisions have to be made looking more than one purchasing lead time ahead, and items are competing for scarce resources under fluctuating demand conditions.

PROCTOR uses question 17 through 21 to determine the existence of external constraints in KBS Foods. An aggregate planning module is considered if at least one constraint is present.

(17) Are there storage constraints that limit the amount of physical inventory you could handle?
(Please key in yes or no): n

(18) And Mr. Smith, are there financial constraints that force you to define a fairly constant

purchasing rate each month?
(Please key in yes or no): n

(19) Are there contracts you sign with individual vendors which force you to define a fairly constant purchasing rate every month?
(Please key in yes or no): ?

(20) Are there supply limits on some of your vendors which force you to anticipate some of your purchasing requirements?
(Please key in yes or no): yes

(21) Do you carry seasonal inventories to absorb demand fluctuations?
(Please key in yes or no): yes

To evaluate the necessity of an aggregate planning module, PROCTOR needs the user's judgement of the importance of the items affected by external constraints and an estimate of the percentage of items affected by these constraints.

(22) Are items involved in external interactions important enough to require a special system? (these items might be very expensive or they could be big sellers)
(Please key in yes or no): yes

(23) Do you know what percentage of your items are affected by these external interactions?
(Please key in a value): 65

A procurement aggregate planning module is needed. This is because you decided that the external constraints of the purchasing department are important.

PROCTOR investigates product aggregation before evaluating aggregate plan feasibility: items and families must be aggregated before a linear programming formulation can be feasible.

(24) Can the items (and/or families) affected by external interactions be grouped into product types (according to similar unit costs, demand patterns, and/or purchasing lead times)?
(Please key in yes or no): y

(25) Now how many product types are there?

Please select one of the following:

1 less than 11
2 between 11 and 20
3 between 21 and 50
4 between 51 and 100
5 more than 100

(Enter here): 4

Notice how PROCTOR makes consistency checks before accepting an answer: it detects an inconsistency between the number of families and the number of products possible through aggregation. Mr. Smith feels that the number of product types is correct and decides to change the number of families.

Mr. Smith, I think I have detected an error.

The number of product types exceeds the number of families.

You may change one or more of the following.

1 "between 51 and 100", the response to question 25 concerning the number of the product types of the purchasing department
2 "between 11 and 50", the response to question 15 concerning the number of the families of the purchasing department

(Please select one or more): 2

So far the following will be changed: The response to question 15 concerning the number of the families of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

(15) Now Mr. Smith, how many families (groups of items) are there?

Please select one of the following:

1 less than 11
2 between 11 and 50
3 between 51 and 100
4 between 101 and 250
5 between 251 and 500
6 more than 500

(Enter here): 4

PROCTOR accepts the change. Previous evaluations are unaffected and PROCTOR proceeds to consider the aggregate plan in detail.

(26) Mr. Smith, do you currently have an aggregate purchasing plan?
(Please key in yes or no): !

Mr. Smith interrupts the session to print information concerning questions 15 and 25. (We omit details to save space.) Notice that changes have been correctly made.

Question 15
concerns the number of the families of the purchasing department
response: between 101 and 250

Question 25
concerns the number of the product types of the purchasing department
response: between 51 and 100

PROCTOR continues the session...
It must determine an appropriate time horizon and time period division for the aggregate plan. These enter into an estimate of the number of variables required.

An existing aggregate plan can sometimes provide insight into appropriate answers.
(26) Now Mr. Smith, do you currently have an aggregate purchasing plan?
(Please key in yes or no): n

(27) Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 1

Mr. Smith decides on a horizon of 6 months. PROCTOR knows that a horizon of at least a year is required when seasonalities are present (see question 21) and indicates the error.

Mr. Smith, I think I have detected an error.

A time horizon of less than 6 months is inappropriate for a situation with seasonal inventories.

You may change one or more of the following.

1 "less than 6 months", the answer to question 27 about the length of the horizon of the aggregate purchasing plan of the purchasing department
2 "present", the answer to question 21 about seasonal-inventories in the purchasing department

(Please select one or more): 1

Please try again....
(27) Now Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 4

Mr. Smith cannot decide on an appropriate horizon. PROCTOR suggests a horizon of at least a year and Mr. Smith agrees.

(28) It is common to do aggregate planning with a year horizon. Is it ok to assume that the time horizon be more than 12 months long?
(Please key in yes or no): yes

Mr. Smith cannot decide on an appropriate time period division. PROCTOR recommends one month which is the most common aggregate planning period.
(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days
10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 12

(30) It is common to do aggregate planning monthly. Is it ok to assume that the time horizon

be divided into 1 month periods?
(Please key in yes or no): y

PROCTOR decides that an LP formulation is infeasible since the estimated number of variables exceeds 1500, the assumed maximum for the number of variables allowed in most commercial LP code.

A procurement aggregate planning module is infeasible. The reasons for the decision are that

1 the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500.
2 a procurement aggregate planning module is needed.

The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered.
(31) It is sometimes useful to aggregate items up to the product level for reporting purposes. Would you like product aggregation to be considered for this reason?
(Please key in yes or no): !

Mr. Smith requests that question 29 be reasked. An longer time period will decrease the number of variables required for the aggregate plan. (Details are omitted to save space.)

So far the following will be changed: The response to question 29 concerning the time period division of the aggregate purchasing plan of the purchasing department.

PROCTOR reasks the question.
(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days
10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 6

PROCTOR delays the redetermination of the feasibility of the LP until it determines the possibility of a middle range forecasting system since aggregate planning support is only possible when demand forecasts can be made.

****

PROCTOR returns to its considerations of an aggregate plan after concluding that middle-range forecasting support is possible. (It continues forecasting investigations in a later part of the session.) An aggregate planning module is feasible and PROCTOR comments on the type of model that must be used.

A procurement aggregate planning module is feasible. The reasons for the decision are that
1 the average number of the variables of the aggregate purchasing plan of the purchasing department is not more than 1500.
2 the average number of the constraints of the aggregate purchasing plan of the purchasing department is not more than 1000.
3 a component to handle middle-range forecasting is possible.
4 a procurement aggregate planning module is needed.

Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. The reasons for the decision are that
1 a procurement aggregate planning module is feasible.
2 external constraints are present.

Product aggregation is needed when the aggregate plan is feasible. In addition, a product disaggregation routine is required for allocating planned procurement amounts to family members.

A component to handle product aggregation in the purchasing department is needed. The reason for the decision is that a procurement aggregate planning module is feasible. Concerning the details of a component to handle product aggregation: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. This is because external constraints are present in the purchasing department and a procurement aggregate planning module is feasible. A module for product disaggregation in the purchasing department is needed. This is because a module for product aggregation is needed and a procurement aggregate planning module is feasible.

****

In another part of the session, PROCTOR considers a lead time determination module. A module will be considered when variable lead time items are present, especially if a significant number of items have variable lead times or if the user feels that these items are important enough to require close control.

(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant
3 fairly variable
4 extremely variable

(Enter here): 3

(45) Now are the items that exhibit variable lead-times important enough to require close control?
(Please key in yes or no): yes

(46) Mr. Smith, can you give a percent estimate of the number of your items that are affected by lead time dependencies?
(Please key in a value): 15

A module for lead time determination is needed. The reason for the decision is that you decided that the items with variable lead times of the purchasing department are important.

With lead time dependencies, lead time forecasting may be possible. PROCTOR investigates dependencies.
(47) And Mr. Smith, does the lead time variability depend on the order size?
(Please key in yes or no): n

(48) Does the lead time variability depend on the season?
(Please key in yes or no): yes

Vendor dependencies exist only when there are multi-vendor items.
(49) Do you have items that can be purchased from several different vendors?
(Please key in yes or no): n

(50) Mr. Smith, do you keep historical records of lead times?
(Please key in yes or no): yes

A forecasting system is possible since seasonal dependencies exist and since lead time records are available.

A lead time forecasting module is possible. The reason for the decision is that lead time dependencies are present. Concerning the details of a component to handle lead time determination: A lead time forecasting system should be implemented for items that have seasonal lead time dependencies. The reasons for the decision are that

1 a lead time forecasting module is possible.
2 seasonal lead time dependencies are present.

PROCTOR notes that it cannot evaluate support for long lead times since it does not know if long lead time items are possible. (It determined that the status of long lead time items was unknown when it investigated the necessity of a middle range forecasting system.)

A decision concerning the type of a module for long lead time determination could not be made. The reason for the decision is that it is not known whether long lead time items are present.

****

PROCTOR has completed the initial investigations into the components of a planning and control system. It returns to toplevel and asks for further instructions: responses can be checked for correctness; evaluations can be summarized.

Mr. Smith decides that KBS's lead times do not have seasonal lead time dependencies; he requests that question 44 be changed.

The current question numbers range from 1 to 72. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 44

So far the following will be changed: The response to question 44 concerning the degree of variability of the lead-times of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant

3 fairly variable
4 extremely variable

(Enter here): 1

An error: Mr. Smith requested that the wrong question be reasked. He interrupts PROCTOR in the middle of a change and requests that question 48 be changed.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

The current question numbers range from 1 to 72. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 48

So far the following will be changed: The response to question 48 concerning seasonal lead time dependencies in the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

PROCTOR must still reask question 44.
(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant
3 fairly variable
4 extremely variable

(Enter here): 3

(48) Now Mr. Smith, does the lead time variability depend on the season?
(Please key in yes or no): n

A lead time forecasting system is inappropriate since there are now no lead time dependencies. Notice that PROCTOR omits all evaluations concerning lead time forecasting and considers alternative variable lead time support. Emergency lead times can be used when items are unexpectedly understocked; safety lead times are useful in providing insurance against stock outs.

(73) Now do your vendors quote an "emergency" lead time for critical items?
(Please key in yes or no): yes

(74) And Mr. Smith, whenever the purchasing lead time is quite uncertain, a safety lead time can be added to the average lead time to take into account the uncertainties associated with lead time calculations. Do you favor the addition of a safety lead time?
(Please key in yes or no): yes

(75) Are there quantity restrictions associated with the emergency lead time?
(Please key in yes or no): yes

(76) Now Mr. Smith, is there a price increase associated with the emergency lead time?
(Please key in yes or no): yes

PROCTOR has redetermined the details of lead time support.

Concerning the details of a component to handle lead time determination: A safety lead time should be added to your best current estimate of the procurement lead time when order amounts are to be determined. Emergency lead times should be used only when items are unexpectedly stocked out. This is because emergency lead-times are present and restrictions are present and you decided that the safety lead-times of the purchasing department are appropriate.

PROCTOR has nothing more to do: it awaits further instructions.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

****

Mr. Smith is not satisfied with the quarter year time period for the aggregate plan and

requests that question 29 be reasked.

The current question numbers range from 1 to 78. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 29

So far the following will be changed: The answer to question 29 about the time period division of the aggregate purchasing plan of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days
10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 5

Unfortunately, Mr. Smith forgot why such an aggregate time period was chosen: an LP was infeasible unless time periods or product types could be aggregated.

A procurement aggregate planning module is infeasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500 and a procurement aggregate planning module is needed. The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered.

In changing the number of time periods, Mr. Smith affected the evaluation of the feasibility of an aggregate plan and in turn, the evaluations for the middle range forecasting system. If an

aggregate plan is infeasible, it may be that no middle range forecasting system is required. PROCTOR, therefore, recomputes evaluations of forecasting that are effected by the change in the evaluation of aggregate plan feasibility. Here, a middle range system is still required since support is needed for a joint ordering interactions module.

Concerning the details of a module for middle-range forecasting: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. This is because a component to handle the forecasting of seasonal items is needed and a component to handle the forecasting of seasonal items is possible and a module for the forecasting of slow-moving items is needed and a module for the forecasting of slow-moving items is possible and a component to handle joint ordering constraints is feasible.

Evaluations of the necessity of product aggregations are affected. Mr. Smith states that he does not want aggregation for reporting purposes. PROCTOR concludes product aggregation is unnecessary: why aggregate if an LP is infeasible?

(31) It is sometimes useful to aggregate items up to the product level for reporting purposes. Would you like product aggregation to be considered for this reason?
(Please key in yes or no): n

A module for product aggregation is unnecessary. This is because a procurement aggregate planning module is infeasible.

PROCTOR returns to the top.

And Mr. Smith, you are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

PROCTOR assumed a time horizon of more than 12 months for the aggregate plan. Mr. Smith specifies a horizon of 6 to 12 months hoping that this will change the number of variables in the LP.

The current question numbers range from 1 to 76. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 27

So far the following will be changed: The answer to question 27 concerning the length of the horizon of the aggregate purchasing plan of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(27) And Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 2

The evaluations have not changed. PROCTOR simply reaffirms its previous evaluations.

A procurement aggregate planning module is infeasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500 and a procurement aggregate planning module is needed. The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered. Concerning the details of a module for middle-range forecasting in the purchasing department: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. This is because a component to handle the forecasting of seasonal items in the purchasing department is needed and a module for the forecasting of seasonal items is possible and a component to handle the forecasting of slow-moving items in the purchasing department is needed and a component to handle the forecasting of slow-moving items in the purchasing department is possible and a procurement aggregate planning module is feasible and a component to handle joint ordering constraints is feasible. A component to handle product aggregation in the purchasing department is unnecessary. This is because a procurement aggregate planning module is infeasible.

You are at top level. Please select one of the following:

1 quit

2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith remembers that he did not specify whether vendor contracts were present. He hopes to remove the infeasibility evaluation by completely specifying the problem.

So far the following will be changed: The response to question 19 concerning vendor contracts.

PROCTOR continues execution. . . .

Notice that this change has absolutely no effect on the evaluation. The change to the number of constraints does not affect the evaluations since an aggregate plan is already infeasible due to too many variables.

(19) Are there contracts you sign with individual vendors which force you to define a fairly constant purchasing rate every month?
(Please key in yes or no): n

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith finally takes the most reasonable course of action. With a little thought, he becomes convinced that there is more product aggregation than he had originally specified. He therefore requests a change to question 25.

So far the following will be changed: The answer to question 25 concerning the number of the product types of the purchasing department.

PROCTOR continues execution. . . .

(25) And Mr. Smith, how many product types are there?

Please select one of the following:

1 less than 11
2 between 11 and 20
3 between 21 and 50
4 between 51 and 100
5 more than 100

(Enter here): 3

PROCTOR recomputes only effected evaluations. It does not review the entire session. Notice that the problem is now feasible but with a different set of conditions: the number of product types has decreased and the number of time periods has increased.

A procurement aggregate planning module is feasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is not more than 1500 and the average number of the constraints of the aggregate purchasing plan of the purchasing department is not more than 1000 and a component to handle middle-range forecasting is possible and a procurement aggregate planning module is needed. Concerning the details of a module for middle-range forecasting in the purchasing department: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. The reasons for the decision are that

1 a component to handle the forecasting of seasonal items is needed and a module for the forecasting of seasonal items is possible.
2 a component to handle the forecasting of slow-moving items is needed and a component to handle the forecasting of slow-moving items is possible.
3 a procurement aggregate planning module is feasible or a component to handle joint ordering constraints is feasible.

A component to handle product aggregation is needed. The reason for the decision is that a procurement aggregate planning module is feasible. A component to handle product disaggregation is needed. This is because a component to handle product aggregation is needed and a procurement aggregate planning module is feasible. Concerning the details of a module for product disaggregation: You should use the Knapsack or Hax-meal disaggregation scheme in allocating planned product type procurement amounts to family and non-family item members of product types. These schemes work best for situations with setup and holding costs such as yours. This is because a module for product disaggregation in the purchasing department is needed and the estimated family and non-family item ordering cost of the purchasing department is more than two dollars and a procurement aggregate planning module is feasible. Concerning the details of a component to handle product aggregation: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. The reasons for the decision are that

1 external constraints are present.
2 a procurement aggregate planning module is feasible.

Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. This is because a procurement aggregate planning module is feasible and external constraints are present.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here):

And the interaction continues. . . .

CHAPTER 3

A DESCRIPTION OF THE QUESTIONNAIRE

In this chapter, we provide an overview of the strategy of the questionnaire as well as a description of its underlying structure.

3.1 Classifying The Firm

The first step in the analysis is to classify the firm according to its activities, its degree of centralization and its size. This classification determines the strategy to be used in the investigation.

The strategy for the analysis is determined primarily by the activities of the firm. Possible activities include any combination of purchasing, manufacturing and distribution. (Notice that the purchasing activity must always be present since no firm is self-sufficient in raw materials.) Distribution affects procurement by creating unusual demands for goods: individual stocking points occasionally decide to hold items independent of the demand of their customers. In such cases, the procurement department can find it impossible to predict future requirements. Issues such as transportation costs become important when distribution activities are present.

If the firm's activities include manufacturing, separate purchasing support is feasible only if demands are independent of the production process. Manufacturing situations with independent demand usually involve simple one step processes like the manufacture of coffee cups or the packaging of pills. For a situation with complex production sequences, even though the demand for end items is smooth and predictable, due

to explosions and assembly lead times, demands for raw materials will be lumpy and erratic (dependent). A material requirements planning system will then be required.

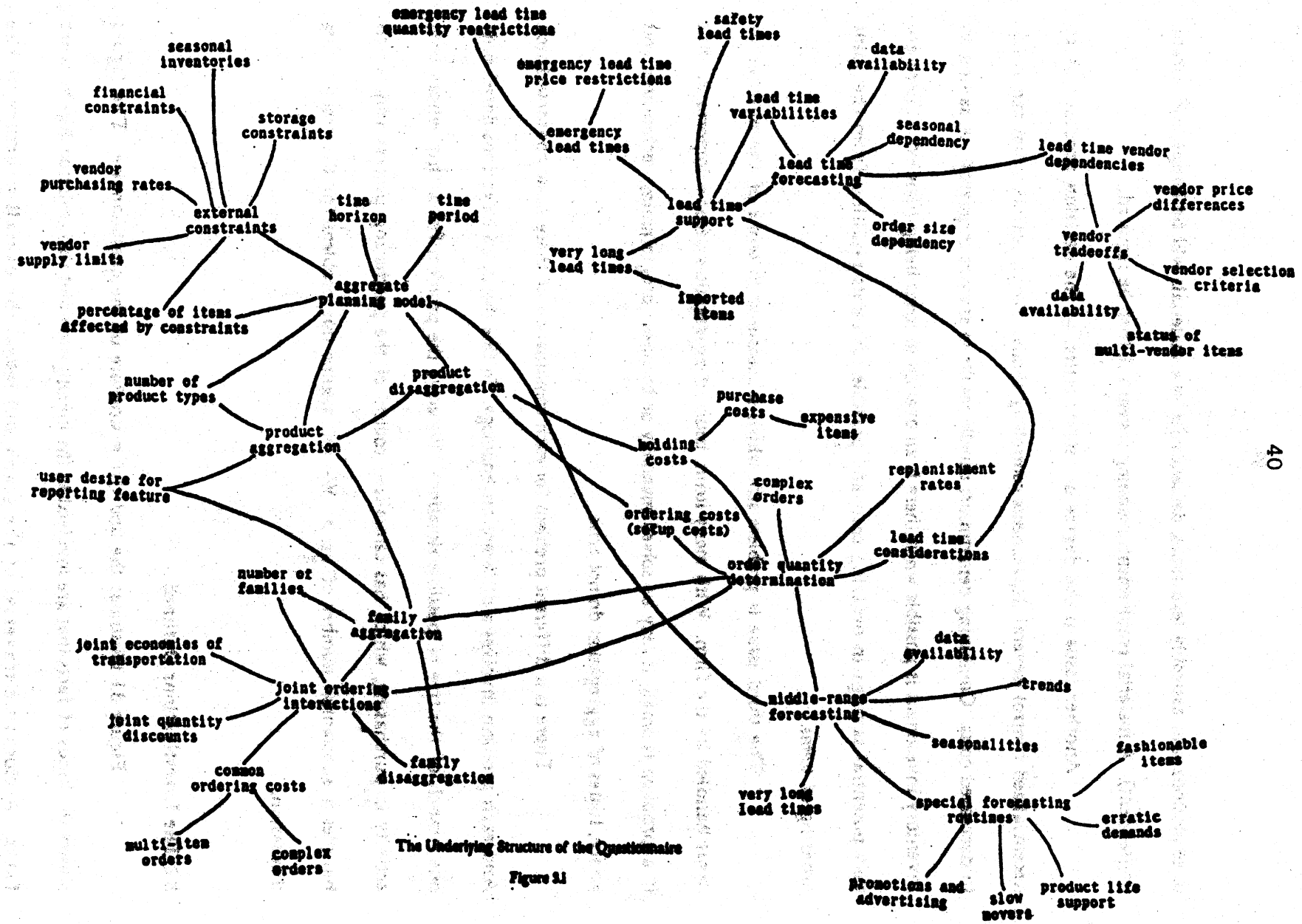
Another issue is the degree of centralization of the decision process. With decentralized control (several departments controlling similar items), centralization can result in decreased costs. Combining departments usually results in savings in payroll. A saving in inventory investment is possible when there is an overlap in items being handled. There are also potential savings in ordering costs and possible discounts resulting from the joint ordering of items.

The third issue is problem size which is measured in terms of the number of items handled by the firm. With many items, issues of aggregation become important. But if a problem is small, it may be solved manually or by linear programming techniques and hence, issues of aggregation do not arise.

There is a different problem for each combination of these basic characteristics. And each problem involves a different methodology. In this thesis, we have considered only one branch of the tree of possible situations. We solve the problem for a firm whose only activity is purchasing, which has centralized control of the purchasing process and which handles a substantial number of items. We will assume this problem for the rest of this discussion.

3.2 The Investigations Outlined

Figure 3.1 illustrates the underlying structure of the questionnaire. The figure shows the kinds of facts that are involved in the investigation and their relationship to other facts. A clockwise traversal of the graph will reveal the overall structure of the



The Underlying Structure of the Questionnaire

Figure 3.1

questionnaire. The questionnaire proceeds by investigating: joint ordering interactions, family aggregations, external constraints, product aggregations, procurement lead time characteristics, vendor characteristics, costs involved in ordering and holding goods, and customer demand characteristics.

Joint ordering interactions are investigated first. In determining the existence of joint ordering interactions, questions concerning joint of economies of transportation from vendors, quantity discounts for multiple items ordered from vendors, and shared ordering costs are considered. Joint ordering support will be considered feasible only when these interactions exist and only if items involved in these interactions are important. Joint ordering support is possible when items involved in joint ordering interactions have similar inventory characteristics. Items may then be aggregated into families for purposes of joint control. The user is asked to estimate the number of families possible and the percentage of items not in families. These are used in an evaluation of feasibility in terms of problem size.

Family aggregation is considered primarily for its use in the joint control of items that exhibit joint ordering interactions. But items may also be aggregated for reporting purposes. This possibility is investigated if joint ordering support is infeasible or not required.

External constraints are investigated next. An aggregate plan is required if one or more of a set of constraints - storage, financial, seasonal or contractual - are present, and if a significant number of items are affected by these constraints.

To evaluate the feasibility of an aggregate plan, PROCTOR requires an estimate of the number of variables and constraints required in the linear program formulation (LP). The user is asked to judge the suitability of various time horizons and

period divisions for the LP. (PROCTOR is careful to suggest a horizon of at least a year when seasonalities exist.) An aggregate plan usually requires more aggregation than family aggregation can offer: product aggregations are therefore considered. Product aggregation is possible only when there exist sets of families and non-family items with similar costs, holding costs, lead times and demand patterns. The user asked to estimate the number of product types that result from aggregations; the number of types enters into the determination of the number of variables in the LP.

Product aggregations are considered both for the aggregate plan and for reporting purposes. A disaggregation routine is required when aggregations are used for planning purposes. Item ordering costs enter into the determination of a suitable component: equalization of run out times will be appropriate for small setup costs. Otherwise, a routine like Knapsack <Bitran and Hax '76> will be suggested.

Having decided on aggregations, the next step is to examine the inventory characteristics. These are lead time characteristics, vendor characteristics and order characteristics.

The first consideration is variable lead times and their dependence on order size, season and vendors. Special procedures will be required to control items with variable lead times. When dependencies exist and lead time records are available, lead time forecasting is the appropriate procedure. For example, with a lead time dependence on season, it may be possible to predict lead times by regression or exponential smoothing. Certain items may have variable lead times with no obvious dependence. These can be controlled by adding a safety lead time to an estimate of their lead time or by taking advantage of emergency lead times. Alternatively, items may be classified as class A and be placed under strict

management control. As part of the lead time investigations, PROCTOR considers items with very long lead times. Imported items may require close supervision, especially if they are high usage items or are expensive.

Another consideration is vendor tradeoffs. When vendors offer different prices and lead times, it may be feasible to set up a system that will perform a tradeoff analysis and then select the appropriate vendor. Questions concerning the availability of records of vendor performance as well as the user criteria for vendor selection are posed to determine the type of procedures to be implemented. If the user criteria for vendor selection is quality, for example, it may not be reasonable to implement a system whose selection criteria is price.

The system next considers support for the determination of order quantities. Questions designed to characterize ordering costs, holding costs and purchasing costs, and to determine the applicability of the Economic Order Quantity (EOQ) formula are posed. First, the properties of relevant costs are obtained from the user. The user is then lead to investigate the EOQ formula as it might apply to his situation. An EOQ routine is possible if setup costs are not too small, if the relative magnitude of setup costs to holding costs is reasonable, and if a middle range forecasting system is possible. Special EOQ formulas are considered for situations with family aggregation, discounts and non-instantaneous replenishment rates. The EOQ will not be appropriate for some items. For these items, the system suggests alternate procedures such as ordering up to a monthly maximum or continuous control.

At this point, the overall framework of the system has been determined. Possible aggregations, disaggregating procedures and special control features have been characterized. The next step is to study the demand since this will influence the forecasting

system which is basic to adequate control.

First, questions of seasonality and trend are examined. If the percentage of seasonal items is insignificant, limited support may be offered, or if only one seasonal pattern exists, a special support system may be adequate. Exponential smoothing with seasonal adjustment requires seasonal indices: the user is asked questions concerning the availability of these indices or data to compute these indices. If limited sales season items are present, it may be advisable to offer support which will prevent overstocking prior to the slack season. The type of support offered is determined by the cost of overage: loss in salvage, storage costs or loss due to scrapping. Items with trends will require forecasting with trend adjustments.

Routines are considered for special items. If fashionable items (high obsolesence, short life) are common, the system should handle them. Promotions and advertising will affect the accuracy of the forecasts. If effects are predictable or if there is heavy investment in advertising, support procedures should be incorporated. Regression will then be mandatory, and if data availability is poor, a tradeoff between the cost of implementation and cost due to poor control will have to be made. If prototype life and death curves exist, support in predicting item growth and decay may be possible and desirable, especially if items exhibit a short life span. Slow movers can be placed in the class C category. Items with erratic demand will require continuous control. If unusually large demands occur, these should be filtered out by a special system.

The strategy is to determine which features would be desirable and are possible in the system. In evaluating the necessity of a component, the system considers the user's judgement of the relative importance of the items.

Data availability is the most important consideration in evaluating the possibility of forecasting support since data is critical to forecasting. For example, without at least three planning horizons of data, regression will not be possible. To handle seasonality, one year of data is normally required to determine seasonal indices. A managerial estimate could be used when data is unavailable, but due to inaccuracies, system performance may be poor. Questions concern the availability of demand and sales records, the cost of data creation, the accuracy of records, the availability of back order records, the length of the history available and the periodicity of the history. Feasible techniques are determined from answers to these questions.

This completes the investigations into system components. The reader may have noticed that all criteria so far have been factual and have involved no biases or preferences. During the investigation, the system asks the user for his judgements concerning the importance of certain items in the firm and for his preferences for the way procedures are to be implemented.

9.3 A Brief Summary

The questionnaire strategy can now be summarized. By interrogating the user, the questionnaire determines the desirability and the feasibility of a set of components in a planning and inventory control system. Feasibility decisions are based on size and data considerations. Components are selected by taking the user's preferences into consideration.

The questionnaire is educational in nature. It presents the approach for the solution of the problem to the user and guides the user in the investigation of various alternatives. This strategy is reasonable since only the user can provide data for his

situation.

Validity checking is important to questionnaire strategy. The validity of answers is checked both to insure that a believable situation is being presented and to insure that the user understands the questions.

CHAPTER 4

A MODEL OF THE QUESTIONNAIRE

This chapter extends the description of chapter 3. By introducing a series of refinements to the description of the previous chapter, we derive a model of the questionnaire that is a basis for the implementation to be discussed in Chapter 5.

4.1 Facts Are Different From Answers

In developing the model of the questionnaire, we found that it was convenient to make a distinction between the user's responses to questions and the facts derived by the system. PROCTOR asks questions to obtain the user's perception of the value of some fact. These responses are checked for correctness and consistency and only then are they used by the system to determine facts concerning the problem.

The distinction simplifies the representation of the questionnaire. It allows us to organize the questionnaire in terms of facts to be derived and not the questions asked to derive these facts. For example, in determining the existence of common ordering costs in the firm, we may simply ask the user if they exist. If the user cannot supply an answer, we can ask if complex orders or multi-item orders exist to perhaps deduce that there are common ordering costs. In describing the questionnaire, we need only mention that the status of common ordering costs must be determined. How we determine this fact is another issue.

The distinction has other implications. The user can change his response to a question but he cannot directly change the value of a fact. By keeping facts separate from responses, we can minimize or eliminate the impact of changes in the user's responses.

Suppose that we had determined that the firm has items with multiple vendors from the response that the average number of vendors supplying an item is "between 10 to 20". If the user changes his response to "between 20 to 30", the fact that there are multiple vendor items does not change. The change in the user's response has no effect on the use of the multi-vendor item fact in other situations.

By making a distinction between facts and responses, we can simplify the checking process. Since the user can only change answers, PROCTOR need only check the consistency of facts at the response level. A response is asserted into the data base only if it is syntactically correct and consistent with other responses. All facts derived from these responses can be assumed to be correct.

4.2 Two Categories of Facts

Two categories of facts can be identified in the questionnaire. The first, the type 1 fact, describes qualitative characteristics of the firm. A type 1 fact will assert that lead times are variable or that quantity discounts are possible in purchasing items from vendors. The second type of fact, the type 2 fact, is more quantitative. These facts describe quantitative information to be used in the evaluation of components for the procurement system and in the determination of other facts. A type 2 fact can state the length of a planning horizon, the number of families possible by aggregation or the percentage of items exhibiting seasonalities.

Figure 4.1 gives a list of type 1 facts to be determined when examining a firm. The indentations show the relation of these type 1 facts to the overall structure of the questionnaire. Notice that all facts are qualitative and characterize the firm. Notice also that

- Firm
  - Activities of the Firm
  - Organization of the Firm
    - Single or Multi-department
    - Centralized or Decentralized Control
  - Departments
    - Overall Problem Size
    - Existence of Item Interactions
      - Truck-load Economies
      - Quantity Discounts
      - Shared Ordering Costs
    - Existence of External Constraints
      - Storage constraints
      - Supply Limits
      - Financial Constraints
      - Contract Commitments
      - Seasonal Inventories
    - Inventory Characteristics
      - Lead-time Characteristics
        - Degree of Variability of Lead-times
        - Dependence on Season, Order-size and Vendor
        - Existence of Imported or Long Lead Time Items
      - Vendor Characteristics
        - Existence of Price Tradeoffs
        - Existence of Lead Time Tradeoffs
      - Order Characteristics
        - Type of Replenishment Rate
        - Existence of Complex Orders
        - Existence of Extremely Expensive Items
    - Demand Characteristics
      - Seasonalities
      - Limited Sales Season Items
      - Trends
      - Erratic Demands
      - Slow Movers
      - Issues of Promotions and Advertising
      - Fashionable Items
      - Item Life Patterns

A List of Type I Facts to be Determined
While Examining the Firm

Figure 4.1

figure 4.1 does not list specific quantities such as the number or percent of items that exhibit these characteristics.

Figure 4.2 gives examples of groups of type 2 facts that are used in the evaluation of components in a procurement system. Type 2 facts can be determined more or less randomly since the absence of a value for a type 2 fact is not as critical for the successful completion of the session. A fact may be derived at a later time and incorporated into the evaluation of a component.

This categorization of facts into two types is important for the model of the questionnaire. In a later section, we will extend this categorization and give rules for deciding when facts are type 1 or type 2.

4.3 A Mapping: The Components of a Procurement System and the Strategy for Investigating the Firm

The questionnaire has an underlying tree structure. Consider figure 4.1 which gave a list of type 1 facts to be determined during the investigation. Figure 4.1 shows groups of related type 1 facts that describe different aspects of the firm. Facts describing the status of truck load economies, joint quantity discounts and shared ordering costs are all related to the joint ordering interactions of the firm. Facts concerning price and lead time tradeoffs describe the firm's vendors.

The questionnaire is structured by combining procedures for determining these type 1 facts into *investigate* activities. The investigate joint ordering interactions activity has, for example, procedures to determine the status of joint economies of transportation, the status of joint quantity discounts and the existence of common ordering costs. Investigate

Aggregate Plan
- Percentage of Items Involved in External Interactions
- User Judgement of the Importance of the Items
- Estimated Number of Types Involved in the Aggregate Plan
- Time Horizon
- Periodicity
- Evaluation of the Possibility of a Middle Range Forecasting System

Middle Range Forecasting System
- Time Horizon
- Periodicity
- Percentage of Seasonal Items
- Percentage of Limited Sales Season Items
- Percentage of Items with Trends
- Data Availability

Order Quantity Calculation Routine
- Evaluation of the Possibility of an EOQ Routine
- Percentage of Expensive Items
- Percentage of Slow Movers
- User Preference for Alternate Procedures

Groups of Type 2 Facts Needed for the Evaluation of Components of a Procurement System

Figure 4.2

activities may be further structured by combining low level investigate activities into more general investigate activities. Thus, the activity that investigates inventory characteristics will investigate lead time characteristics, vendor characteristics and order characteristics. The ultimate investigate activity is the activity to investigate the firm.

The hierarchical structure of investigate activities is shown in figure 4.3. Type 1 facts can be determined by each activity of this tree. At the investigate the purchasing departments activity, we determine the number of purchasing departments. At the investigate the demand characteristics activity, we determine type 1 facts concerning the demand patterns for items in the firm.

The questionnaire is also structured around groups of type 2 facts. Consider the basic components of a procurement system. According to Hax's methodology, they can include:

- a method for family aggregation
- a method for type aggregation
- a family-item disaggregation routine
- a type-family disaggregation routine
- an aggregate planning procedure
- a lead-time forecasting module
- an order quantity calculation module
- a vendor selection routine
- a medium forecasting system

This list could have been further refined. An order quantity routine can include an Economic Order Quantity calculation routine, a routine for expensive items and a routine for slow movers.

Groups of type 2 facts enter into the evaluations that occur when PROCTOR considers these components. When we consider aggregate planning support, we require facts concerning the percentage of items that are affected by external constraints, the time horizon

Investigate the firm

Investigate the departments of the firm

Investigate the purchasing departments of the firm

Investigate a particular purchasing department

Investigate the item constraints

Investigate the joint ordering constraints

Investigate the external constraints

Investigate the inventory characteristics

Investigate the lead time characteristics

Investigate the vendor characteristics

Investigate the costs and order characteristics

Investigate the demand characteristics

The Structure of Investigate Activities

Figure 4.3

and periodicity of the aggregate plan, the number of product types as well as a judgement concerning the importance of the items that are affected by external constraints. We call groups of evaluations *consider* activities. When we evaluate the feasibility, necessity and type of aggregate planning component, we are really *considering* the aggregate planning component.

Consider activities may be structured according to dependencies that exist between modules in a general planning and control system. (See figure 4.4.) From figure 4.3 and figure 4.4, we can see that there is a one to one correspondence between the structure of investigate activities and the structure of consider activities. In the "context" of each investigate activity, certain consider activities can be initiated. In investigating external constraints, for example, we naturally consider an aggregate planning component, a product aggregation component and a product disaggregation component.

The underlying structure of the questionnaire should now be clear. Figure 4.3 is an overall plan for the investigation of the firm. While executing the plan, type 1 facts are determined. Considerations into components of the procurement system are initiated depending on the value of these type 1 facts. To evaluate components, type 2 facts are determined. The implication of the model is that no additional structure is needed for the evaluation of components of the procurement system. We use the tree of investigate activities as the plan for the investigation of the firm. Investigate activities can initiate other investigates as well as considerations into components for the procurement system.

It may seem at this point that the questionnaire is completely hierarchical: that individual investigations may be done independent of other investigations. Unfortunately, non-linearities do exist.

Firm system

Department system

Planning module

Family-item aggregation-disaggregation routine

Family aggregation method

Family-item disaggregation method

Aggregate planning routine

Product-family disaggregation routine

Product aggregation method

Product disaggregation method

Scheduling routine

Lead time forecasting routine

Vendor selection routine

Order quantity calculation routine

Forecasting system

Medium range forecasting system

Short range forecasting system

The Structure of Components of a Procurement System

Figure 4.4

As an example, consider the evaluations for the type to family disaggregation module. In deciding on a Knapsack or equalization of run out time disaggregation method, we examine both holding costs and ordering costs. (For small ordering costs or for situations where ordering costs are small compared to holding costs, equalization of run out times is the appropriate disaggregation method.) Notice, however, that costs are usually determined by the activity that investigates costs. When ordering costs are used in the evaluations for disaggregation, they are used "out of context". This non-linearity will complicate our theory only slightly. Its implications are described in a later section.

4.4 Type 1 and Type 2 Facts: Their Impact on Strategy

We stated previously that type 1 facts are qualitative facts concerning features of the firm. Type 1 facts influence the strategy of the investigation. But how?

Consider some typical type 1 facts. They can describe the size of the firm, the activities of the firm, the variability of its procurement lead times and the demand characteristics of the firm's items. These facts influence the strategy of the questionnaire. A one item system, for example, is so different from a multi-item system that a completely different strategy for investigation is appropriate in each case. The strategy for investigating item demand is influenced by type 1 facts concerning seasonal items and items with trends.

Depending on their detail, type 1 facts are derived at different levels in the tree of figure 4.3. Characteristics concerning the basic organization of the firm are derived at the upper level investigate the firm and investigate the departments activities. The more detailed fact concerning the variability of lead times is derived at the low level investigate

lead time characteristics activity. The scope of a type 1 fact seems to correspond to the level at which it is derived in the investigate tree. Thus, the fact concerning the variability of lead times will influence the strategy of investigations into lead times. The fact concerning the activity of the firm will influence the strategy of all activities below the investigate the firm activity.

Type 1 facts influence the strategy by determining the procedures to be used in an investigation. Thus, the procedures that determine facts and evaluate components in the investigate external constraints activity depend in part on the status of external constraints in the firm: only a minor amount of processing is done by the investigate external constraints activity when external constraints are absent. The procedure for an activity depends on only a limited number of facts (two or three at the most) and only on features that are necessary to distinguish between the various procedures for the activity: the procedure for the investigate external constraints activity will not depend on the degree of variability of lead times.

While type 1 facts determine strategy by influencing the selection of a procedure for an activity, type 2 facts do not. Type 2 facts are data that is used during the execution of a procedure. Suppose that we have decided that an aggregate purchasing plan is necessary since a significant number of items are affected by external constraints. We must next determine if it is actually feasible. The number of variables in the linear programming formulation (a type 2 fact) enters into this evaluation. We make our decision by comparing this number with some upper bound that is determined by limitations of currently available LP code. The number of variables in no way affects the selection of a procedure for evaluating the feasibility of an aggregate purchasing plan. We use the same procedure

regardless of its value.

Other type 2 facts are similar. The number of families resulting from family aggregation determines if a procedure for joint ordering is realistic. But it does not determine the procedure for making this feasibility decision. The type 1 fact concerning the possibility of aggregating items into families determines the procedure used. If family aggregation is impossible, the procedure is to simply assert that joint ordering support is infeasible.

We now see how this description of type 1 and type 2 facts relates to the categorization described in section 4.2. Type 1 facts influence strategy and by their nature they must be qualitative. We need not deal with exact numbers but with ranges and generalizations when deciding on a procedure for an activity. In selecting a procedure, knowing we have many or few items is just as useful as knowing we have 4 or 437 items. Type 2 facts enter directly into evaluations and are by their nature quantitative. To evaluate the feasibility of a component to handle joint ordering interactions, we need at least an estimate of the percentage of items involved in these interactions.

Type 2 facts never influence strategy. Type 1 facts, however, may both influence strategy and enter into the evaluation of components for a procurement system. Consider again the evaluations for the aggregate plan. A procedure for determining the details of the aggregate plan depends on whether external constraints even exist (a type 1 fact). In determining the details of the plan, we need both type 2 facts such as the number of items involved in external interactions and type 1 facts describing the actual constraints. The latter fact determines the kinds of constraints to be included in the LP formulation.

The rule for classifying a fact as type 1 or type 2 is now clear: if a fact enters

into the selection of a procedure for an activity, it is a type 1 fact otherwise it is type 2. Responses are type 2 facts since they never enter directly into the selection of a procedure. Notice also that all evaluations are type 2 since they cannot determine strategy. If evaluations were type 1 facts, it would not be possible for PROCTOR to continue an investigation without making a definite decision at each step in the investigation. The distinction to be made is that facts related to the possibility of a component influence the strategy but the actual evaluations of the component do not. So an aggregate plan is possible if external constraints exist. Type 2 facts determine if an aggregate plan is actually required. The status of external constraints influences the subsequent strategy and launches an investigation into a medium range forecasting system.

The categorization of type 1 and type 2 has implications to changing answers. A change in a response can affect the value of a type 1 or type 2 fact or both. If a change affects a type 1 fact, then certain other facts may be invalidated. Facts determined during the evaluation of an aggregate plan become invalid if constraints do not exist. Vendor tradeoffs are impossible if multiple vendors do not exist. A type 1 fact may affect a type 2 fact directly. If the type 1 fact is used in the determination of a type 2 fact (as is the case with the evaluation of the details of an aggregate planning module), then the value of the type 2 fact is affected directly. A type 2 fact may enter in the determination of either type 1 or type 2 facts. A change in the type 2 fact will affect these facts directly.

4.5 Changing Answers: Environments and Direct Dependencies

In the previous section, we described how a type 1 fact affects the selection of a procedure and how a type 2 fact enters only into the execution of this procedure. We also

described the implications of this categorization of facts to changing answers during the investigation. In this section, we formalize these notions.

As an example, consider the investigate lead times activity. The procedures to be used in the investigation depend on the degree of variability of lead times and on the status of lead time dependencies. If lead times are constant, we can simply deduce that a component to project lead times will not be required. Suppose, however, that there are variabilities. Lead times may then depend on season, on order size and on vendors. These dependencies can exist only when lead times are variable. In addition, vendor dependencies can exist only when the firm has multi-vendor items.

There are various approaches to selecting a component to handle variable lead times. A forecasting module is possible if lead time dependencies exist. For variable lead times with no dependencies, a possible solution is to add a safety lead time to the best current estimate of the item lead time. The procedures for determining the possibility, necessity and type of a component for forecasting lead times are determined by the lead time dependencies. When dependencies are absent, the procedure is to simply assert that forecasting is impossible. When the status of dependencies is unknown, we cannot make any evaluations. We simply assert that evaluations cannot be made. More complicated procedures are used when dependencies do exist.

In evaluating the necessity of a forecasting component, we use facts like the percentage of items that exhibit these dependencies and their relative dollar value (either actual or based on user judgement). The evaluation of the possibility of a component is determined by the availability of lead time records and the evaluation of the necessity of the component. The type of a forecasting procedure is determined by the details of lead time

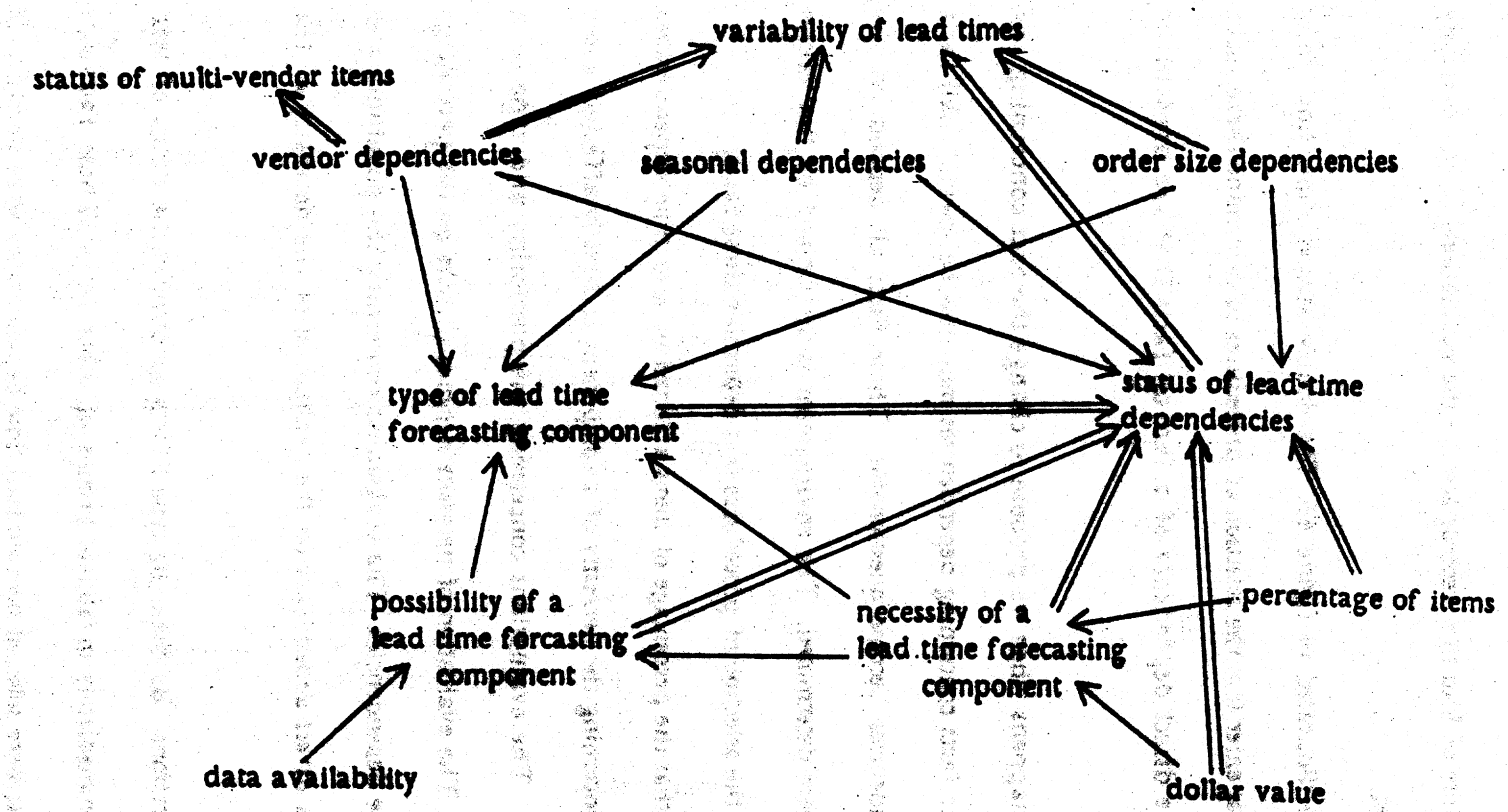
dependencies, by the availability of lead time records and by the evaluations of the necessity and possibility of a component.

These relations are illustrated in figure 4.5. The double arrows show how facts depend on the type 1 facts that enter into the selection of procedures to determine these facts. The single arrows show the direct dependency of a fact on facts that are used in its determination.

Consider what happens when we propose to change the fact concerning the variability of lead times. The facts concerning dependencies may now be invalid. All facts that depend on these dependencies become questionable. These facts all depend on the *environment* in which they were determined. The environment is determined by the values of type 1 facts that enter into the selection of procedures that determine these facts.

Suppose instead that the percentage of items affected by lead time dependencies is altered. The evaluation concerning the necessity of a component is directly affected when we change this type 2 fact. The evaluations concerning the possibility and type of a component are also affected. The evaluation of necessity *depends directly* on the percentage of items affected by lead time dependencies. The evaluations concerning the possibility and type of a component have a *direct dependency* on the evaluation of the necessity of the component.

Notice the implications. By changing type 1 facts concerning the status of lead time dependencies, we can immediately invalidate groups of other facts. These facts are determined by procedures that were selected because lead time dependencies were present. If lead time dependencies were absent, these facts would never have been determined unless alternate procedures required them. When dependencies are absent, there is no fact



A ⟸ B *means* A *enters into the selection of a procedure for* B

C ⟵ D *means* D *enters into the determination of* C

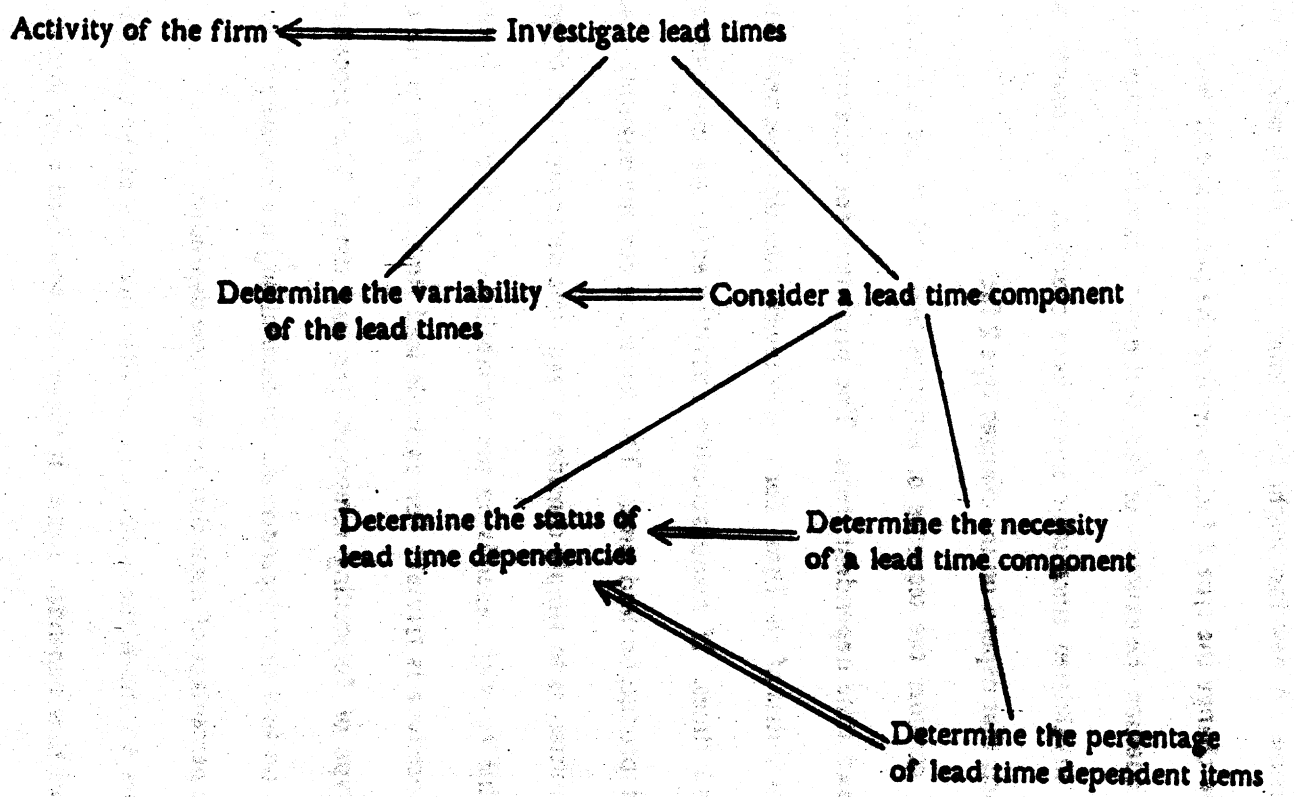
Dependencies in the Evaluation of A Forecasting Component for Lead Times

Figure 4.5

concerning the percentage of lead time dependent items. Facts are not just invalidated: new facts become possible. A new fact might be determined by a newly selected procedure. In contrast, when we change the type 2 fact concerning the percentage of lead time dependent items, we do not question the existence of facts that depend directly on this type 2 fact. The facts are simply invalidated since some inputs have changed. To recover, we need only recompute the facts that depend on the changed type 2 fact.

Now consider the sequence of activities that lead to the determination of the percentage of lead time dependent items. The procedure for investigating lead times depends on the activities of the firm. For a procurement situation, we need only investigate procurement lead times. If manufacturing activities exist, we must investigate both procurement and production lead times. The procedure for investigating lead times in a procurement situation is to simply consider a lead time determination component. The procedure for this activity depends on the variability of lead times. If lead times are constant, the procedure is trivial. For variable lead times, we determine the necessity, possibility and type of forecasting component for lead times. The procedures for these activities depend on lead time dependencies. In determining the necessity of the component, we determine the percentage of items that are lead time dependent.

Figure 4.6 shows the sequence of activities that lead to the determination of the percentage of lead time dependent items. It shows also how facts enter into the selection of procedures for these activities. (These are illustrated by the double arrows.) We see that the environment of a fact is determined not only by the facts that enter into the selection of a procedure for the determination of that fact, but also by all facts that enter into the selection of procedures of activities that lead to the determination of that fact. The environment for



The Sequence of Events to the Determination of a Fact
Figure 4.6

the percentage of lead time dependent items includes facts concerning the activities of the firm, the variability of lead times and the status of lead time dependencies.

A type 1 fact can appear in the environments of both type 1 and type 2 facts. These facts can be invalidated by changing the type 1 fact. By invalidating a type 1 fact, we can similarly invalidate other type 1 and type 2 facts. The process eventually terminates. New facts are now possible since different procedures may now be used. Clearly the side effects from changing a type 1 fact can be extensive enough to warrant a review of the session. In reviewing the session, we redetermine the values of all facts whose environments have changed. (This does not imply that we reask all questions!) We also determine new facts that appear in procedures that are now selected.

It is usually unnecessary to recompute the session when we change a type 2 fact. In determining the effect of a change to a type 2 fact, we trace back through direct dependencies to find all facts the depend either directly or indirectly on this type 2 fact. These facts can then be sorted according to their dependencies and are recomputed.

In changing a type 2 fact, we may indirectly change the value of a type 1 fact. For example, many type 1 facts depend directly on responses which are type 2 facts. We revert to the type 1 change procedure when a change in a type 2 fact results in a change to a type 1 fact.

We mentioned previously that non-linearities exist in the questionnaire. Suppose that while investigating lead time vendor dependencies, we determine the status of multi-vendor items. The environment for the status of multi-vendor items will then include the fact concerning the variability of lead times. Clearly multi-vendor items can exist regardless of the degree of variability of lead times. The problem arises because the status of multi-

vendor items is determined "out of context". The environment for this fact would be correct if the fact was determined during the investigation of vendor tradeoffs. The problem is solved by specifying an explicit environment for facts that can be determined out of context. The value of such a fact is assumed to depend on only the explicit environment and not on the computed environment.

4.6 And Other Things

4.6.1 The Basic Activities

In the above the discussion, I have made reference to activities that appear in the questionnaire.

The basic activities in the questionnaire are: investigate, determine, ask, consider, check, and explain. Notice that we have no activity for evaluations. I have chosen to use determine for this purpose: to evaluate a component, we actually determine the evaluation of that component. Each activity depends on zero or more type 1 facts that determine the procedure to be used for its execution.

The procedure for ask is trivial. Ask merely presents a question to the user, checks the answer for syntactic correctness and consistency, and asserts it into the data base with the correct environment. Ask will not reask a question if it knows an answer and the answer is still valid, ie. its environment is still valid.

The procedure for a determine consists of a set of methods for determining the value of a type 1 or a type 2 fact. Like ask, determine will first access the data base to see if the fact has a valid value. Determine simply exits if a valid value exists. Otherwise, determine tries each method until it determines the value of the fact. Determine asserts the

determined value of this fact into the data base with a record of the environment and direct dependencies. There are direct dependencies between the fact to be determined and all facts that are referenced during the execution of the methods.

Check does consistency checking for the system. It is used by the ask activity to verify that a response is semantically correct and consistent with other information. The recovery for an inconsistency is to either reask the question or to allow the user to change a previous response.

Consider initiates evaluations into components. Its procedure is a list of determine activities for facts concerning the evaluation of the feasibility, type, possibility and necessity of the components. Investigate is a set of ordered determine, consider and investigate activities.

Explain is a simple activity that merely asks the user if he needs an explanation and if so prints out text. Explain can be invoked by any activity.

4.6.2 Facts and Their Relation to Entities

We have discussed the basic process of determining facts. As they are gathered and validated, facts are asserted into the data base. In a situation with one firm and one department, there is no confusion since each piece of information applies simultaneously to the firm and the department. But what happens if there are two purchasing departments?

When we investigate the departments of a firm, we investigate their inventory characteristics. We may assert, for example, that lead times of one are constant and the other are variable.

Later, when all departments have been examined, we may look at facts concerning

lead times over all departments. We would like to look at an aggregation of characteristics over members of a set. In our case, the set is the set of purchasing departments of the firm. The aggregation may be defined as a conjunction of all facts concerning the variability of item lead times. Alternatively, determine activities may be provided for performing more specialized aggregations. For example, a fact concerning the variability of lead times of a department may be included only if the department controls more than 10 percent of all items of the firm.

We can implement these ideas by recognizing that there are two basic types of investigate activities in the questionnaire. We can investigate an *entity* or a set of entities where entity is a firm, a department of a firm, or a purchasing department of the firm. We may also investigate facts concerning these entities. We investigate, for example, the inventory characteristics of a specific purchasing department.

Entities can be organized into a tree or hierarchy that corresponds at a very aggregate level to the structure of the investigate tree. Because of this structure, it is possible to implement the questionnaire without passing variables. In investigating a firm, PROCTOR first identifies the firm. All facts that are determined during the investigate the firm activity are assumed to refer to this firm unless we explicitly reference a fact concerning another entity.

While investigating the firm, we may investigate a purchasing department. All facts determined within this activity apply to that department. When we complete the investigation of the department, we again use the firm as the default entity. At the firm level, we may reference facts concerning each of its departments.

In the implementation, I considered the case with one firm and one purchasing

department. I did not investigate notions of aggregation with respect to several departments. I did, however, implement the basic mechanisms for handling entities. Entities prove useful in providing a structure for organizing facts in the data base and in simplifying the dumping of the data base.

CHAPTER 5

IMPLEMENTATION OF THE MODEL

This chapter describes the technical details of the implementation of PROCTOR in OWL. Readers unfamiliar with OWL are referred to the article by Hawkinson for a description of the implementation of OWL in LISP and for a summary of the terminology that we use in this chapter.

5.1 Overview of The Implementation

Conceptually, PROCTOR investigates a firm by making a top-down left-right traversal of a tree such as that in figure 5.1a. Illustrated is the tree for determining the status of emergency lead time restrictions. This tree is not prestored explicitly in the OWL data base: the tree varies dynamically according to what PROCTOR knows. Figure 5.1b, for example, shows the tree as it would appear if the status of emergency lead times and the status of emergency lead time price increases were known.

The tree grows when a procedure for an activity is selected. For a consider or investigate activity, the procedure is simply a list of activities to be executed. These activities become sons of the original activity. For a determine activity, we may have several methods to be tried. These methods have activities which become sons of the determine activity. The lowest level activities are ask and assert; they form the leaves of the tree.

Determine the status of emergency lead time restrictions.

Determine the status of emergency lead times.
Ask the status of emergency lead times.
Assert the response to asking the status of emergency lead times.

Determine the status of emergency lead time quantity restrictions.
Ask the status of emergency lead time quantity restrictions.
Assert the response to asking the status of emergency lead time quantity restrictions.

Determine the status of emergency lead time price increases.
Ask the status of emergency lead time price increases.
Assert the response to asking the status of emergency lead time price increases.

Assert that emergency lead time restrictions are present

A Portion of the Execution Tree

Figure 5.1a

Determine the status of emergency lead time restictions.

Determine the status of emergency lead time quantity restrictions.
Ask the status of emergency lead time quantity restrictions.
Assert the response to asking the status of emergency lead time quantity restrictions.

Assert that emergency lead time restrictions are present

The Execution Tree for a Different Situation

Figure 5.1b

5.1.1 Two Modes of Operation

PROCTOR has two modes of operation: toplevel mode and analysis mode. The toplevel cycle is trivial: PROCTOR repeatedly asks the user for a request. In toplevel mode, the user may request that PROCTOR dump the data base, change answers, print evaluations, or enter analysis mode to start or continue the investigation of a firm. Analysis mode can at any time be interrupted for a return to toplevel. Figure 5.2 presents a flowchart which shows the basic cycle of PROCTOR in analysis mode.

5.1.2 The Basic Execution Cycle

At the beginning of its cycle, PROCTOR selects an activity for execution from an *event tree*. (For purposes of this overview, we will assume that the event tree is a stack.) Let us assume that the activity to be executed is the activity to determine the status of emergency lead time restrictions. Figure 5.3 gives an OWL representation of this activity. The English translation appears in figure 5.4.

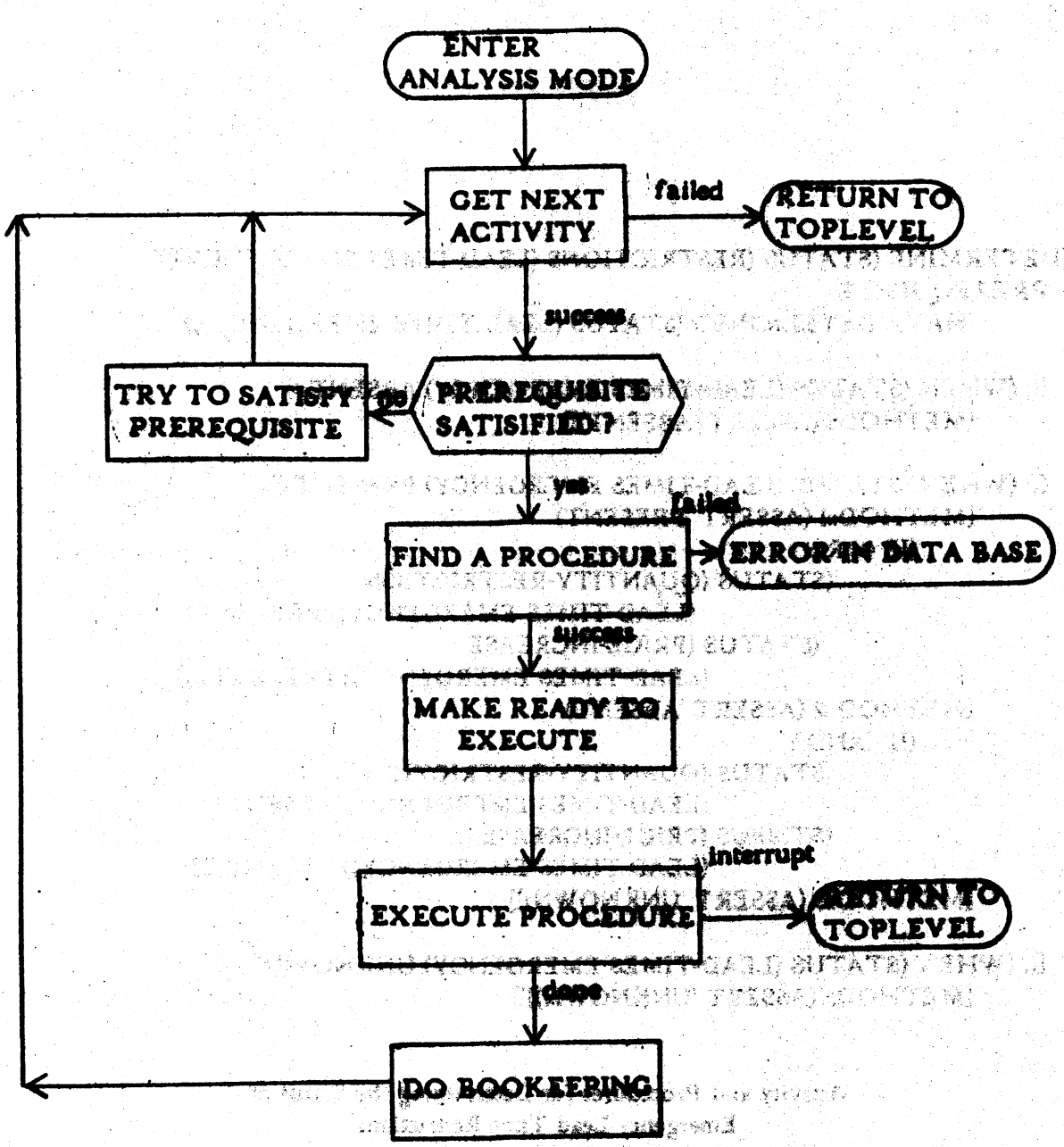
This activity has a *prerequisite* that must be satisfied before a procedure may be selected. The prerequisite states that the status of emergency lead times must have been determined: before a procedure is selected, it should have a legal value or be unknown. Suppose that the value of the status of emergency lead times is undetermined. PROCTOR will satisfy the prerequisite by making

```
[(DETERMINE (STATUS (LEAD-TIMES EMERGENCY)))]
```

the next activity. PROCTOR resumes execution of

```
[(DETERMINE (STATUS (RESTRICTIONS (LEAD-TIMES EMERGENCY)))))]
```

once the status of emergency lead times is determined.



The Basic Execution Cycle of PROCTOR

Figure 5.2

```
[(DETERMINE (STATUS (RESTRICTIONS (LEAD-TIMES EMERGENCY))))
  PREREQUISITE:
       (HAVE-DETERMINED (STATUS (LEAD-TIMES EMERGENCY)))

  [(: (WHEN (STATUS (LEAD-TIMES EMERGENCY) ABSENT)))
       [METHOD:: (ASSERT 'ABSENT)]]

  [(: (WHEN (STATUS (LEAD-TIMES EMERGENCY) PRESENT)))
       [METHOD:1 (ASSERT 'PRESENT)
            (IF (OR:::
                 (STATUS (QUANTITY-RESTRICTION
                              (LEAD-TIMES EMERGENCY)) PRESENT)
                 (STATUS (PRICE-INCREASE
                              (LEAD-TIMES EMERGENCY)) PRESENT)))]
       [METHOD::2 (ASSERT 'ABSENT)
            (IF (AND:::
                 (STATUS (QUANTITY-RESTRICTION
                              (LEAD-TIMES EMERGENCY)) ABSENT)
                 (STATUS (PRICE-INCREASE
                              (LEAD-TIMES EMERGENCY)) ABSENT)))]
       [METHOD:3 (ASSERT 'UNKNOWN)]]

  [(: (WHEN (STATUS (LEAD-TIMES EMERGENCY) UNKNOWN)))
       [METHOD:: (ASSERT 'UNKNOWN)]]
```

Activity and Procedures for Determining the Status of
Emergency Lead Time Restrictions

Figure 5.3

Determine the status of emergency lead time restrictions:
The prerequisite is that the status of emergency lead times be determined.

Determine the status of emergency lead time restrictions when emergency lead times are absent:
Method: Assert that they are absent.

Determine the status of emergency lead time restrictions when emergency lead times are present:
Method 1: Assert that they are present if emergency lead time quantity restrictions are present or emergency lead time price increases are present.

Method 2: Assert that they are absent if emergency lead time quantity restrictions are absent and emergency lead time price increases are absent.

Method 3: Assert that the status of emergency lead time quantity restrictions and the status of emergency lead time price increases is unknown.

Determine the status of emergency lead time restrictions when the status of emergency lead times is unknown.
Method: Assert that the status is unknown.

English Version of the Activity for Determining the Status of Emergency Lead time Restrictions

Figure 5.4

Suppose now that emergency lead times are known to be present. The prerequisite is satisfied and PROCTOR can select a procedure. Procedures are activities that are specialized by a *when condition*, a predicate concerning the type 1 facts that are in the prerequisite. PROCTOR selects

```
[((DETERMINE (STATUS (RESTRICTIONS (LEAD-TIMES EMERGENCY))))
          (WHEN (STATUS (LEAD-TIMES EMERGENCY) PRESENT)))]
```

as the procedure for determining the status of emergency lead time restrictions.

PROCTOR is now ready to execute. It updates the event tree to show that a procedure has been selected and that execution has started, and passes the procedure to an interpreter for determine activities.

The determine interpreter executes methods of the procedure until one succeeds in asserting a value. Notice that a method may have an optional condition: a method is tried only if its associated condition is true. Notice also that it is possible that a fact in a condition might be undetermined. The determine interpreter can suspend the execution of an activity to request that PROCTOR determine an undetermined fact. (The event tree proves useful for saving the state of execution of the suspended procedure.) The determine interpreter continues execution once such a fact has been determined.

Let us suppose that emergency lead time price restrictions are known to be present and that the status of emergency lead time quantity restrictions is unknown.

```
[(IF (OR:::
     (STATUS (QUANTITY-RESTRICTION (LEAD-TIMES EMERGENCY)) PRESENT)
     (STATUS (PRICE-INCREASE (LEAD-TIMES EMERGENCY)) PRESENT)))]
```

evaluates to TRUE and PRESENT is asserted as the value for the status of emergency lead time restrictions. The current environment and the appropriate direct dependencies are

recorded with this value.

The event tree is updated to reflect the completion of the execution of the determine status of emergency lead time restrictions activity and the cycle repeats.

5.2 The Basic Representation for Activities and Procedures

PROCTOR's activities have the same basic representation. This is illustrated by the example of figure 5.3 and the following examples:

```
[(INVESTIGATE (CONSTRAINTS (DEPARTMENT PURCHASING)))
  [METHOD:
    (EXPLAIN (CATEGORIES AGGREGATION))
    (EXPLAIN (CONSTRAINTS JOINT-ORDERING))
    (INVESTIGATE ((CONSTRAINTS JOINT-ORDERING)
                  (DEPARTMENT PURCHASING)))
    (EXPLAIN (CONSTRAINTS EXTERNAL))
    (INVESTIGATE ((CONSTRAINTS EXTERNAL) (DEPARTMENT PURCHASING)))]]

[(DETERMINE (STATUS (RECORDS SALES)))
  DEPENDENCIES: NONE
  [METHOD: (ASSERT (RESPONSE (ASK (STATUS (RECORDS SALES)))))]]
```

An activity may have optional prerequisite and dependency attributes. The prerequisite is a conjunction of assertions that must be true before PROCTOR can select a procedure for the activity. The assertions specify that certain type 1 facts must either be determined or known.

```
[(HAVE-DETERMINED (STATUS (LEAD-TIMES EMERGENCY)))],
```

for example, states that the status of emergency lead times must have a legal value or be unknown. We use HAVE-DETERMINED for this example because a procedure exists to explicitly handle the case when the status of emergency lead times is unknown. An assertion can also specify that a fact must be known. In this case, the fact must have a legal value

before a procedure is selected. PROCTOR tries to satisfy the prerequisite predicate by determining the values of undetermined facts before selecting a procedure.

The dependency attribute specifies an explicit environment for an activity. It is a conjunction of type 1 facts that can be used to create an environment to override the general environment mechanism described in Chapter 4. PROCTOR determines the values of all facts in the explicit environment before it executes an activity. In the above example, we state that the status of sales records has no dependency. This fact does not have an explicit environment and does not inherit a general environment.

A procedure for the execution of an activity can be either the activity itself or a *when specialization* of the activity. In the example of figure 5.3,

```
[((DETERMINE (STATUS (RESTRICTIONS (LEAD-TIMES EMERGENCY))))
          (WHEN (STATUS (LEAD-TIMES EMERGENCY) PRESENT)))]
```

is a *when specialization* and

```
[(WHEN (STATUS (LEAD-TIMES EMERGENCY) PRESENT))]
```

must be true for this when specialization to be selected.

Each when specialization of an activity as well as the activity itself can have a method. A when specialization may inherit methods and method details from its parent activity. Thus, for situations where only 1 or 2 when specializations need special methods, we define these when specializations and let other cases use the method of the activity. An activity need not have any when specializations.

```
[(INVESTIGATE (CONSTRAINTS (DEPARTMENT PURCHASING)))]
```

is both an activity and a procedure for the activity. Notice that it is an error if a procedure with a method cannot be selected.

5.3 Data Structures Used by PROCTOR

PROCTOR uses several data structures during its execution. These are the *event tree*, the *entity tree*, a set of *environment trees* and a *used-by lattice*. The event tree controls the execution cycle of PROCTOR; the entity tree organizes facts in the data base and relates them to the firm and its purchasing department; the environment tree and used-by lattice are used in the change answers procedure. All structures are implemented in the OWL data base.

5.3.1 The Event Tree

The event tree controls the execution of PROCTOR. Figure 5.5a and 5.5b show a portion of this tree as it might appear during the execution of the investigate constraints activity. (PROCTOR has just determined the necessity and feasibility of a component to handle joint ordering constraints. It is about to evaluate the type of component necessary to handle these interactions.)

Each node of the tree corresponds to an event of the interpreter which in turn corresponds to the execution of an activity. The tree is doubly linked to make possible upwards and downward traversal without the use of auxiliary stacks.

There is a continuation attribute associated with each node of the event tree. This attribute is a LIFO list of activities that must be executed before the completion of the event. Activities are added to a continuation by PROCTOR to satisfy a prerequisite, by individual activities during their execution and by the change answers routine.

PROCTOR maintains two pointers into the event tree. TOP-EVENT points to the topmost event of the tree. This event corresponds to the activity

```
[(event 10)
   calling-event%: (event 8)
   called-events%: (event 11) (event 12)
   activity%: (investigate (constraints (department purchasing)))
   continuation%: (explain (constraints external))
                  (investigate ((constraints external)(department purchasing)))]

[(event 11)
   calling-event%: (event 10)
   activity%: (explain (constraints joint-ordering))]

[(event 12)
   calling-event%: (event 10)
   called-events%: (event 13)
   activity%: (investigate ((constraints joint-ordering)(department purchasing)))
   continuation%: (consider (aggregation family))]

[(event 13)
   calling-event%: (event 12)
   called-events%: (event 14) (event 17) (event 20) (event 24)
   activity%: (consider (constraints joint-ordering))]

[(event 14)
   calling-event%: (event 13)
   activity%: (determine (status (constraints joint-ordering)))
   . . . .]

[(event 17)
   calling-event%: (event 13)
   activity%: (determine (evaluation
                  (necessity (system-component (handle (constraints joint-ordering))))))
   procedure%: ((determine (evaluation (necessity (system-component
                  (handle (constraints joint-ordering)))))
                  (when (status (constraints joint-ordering) present)))
   selection-values%: (status ((constraints joint-ordering)
                  (((department purchasing) 1)((firm 1)(session 1)))) present)]
```

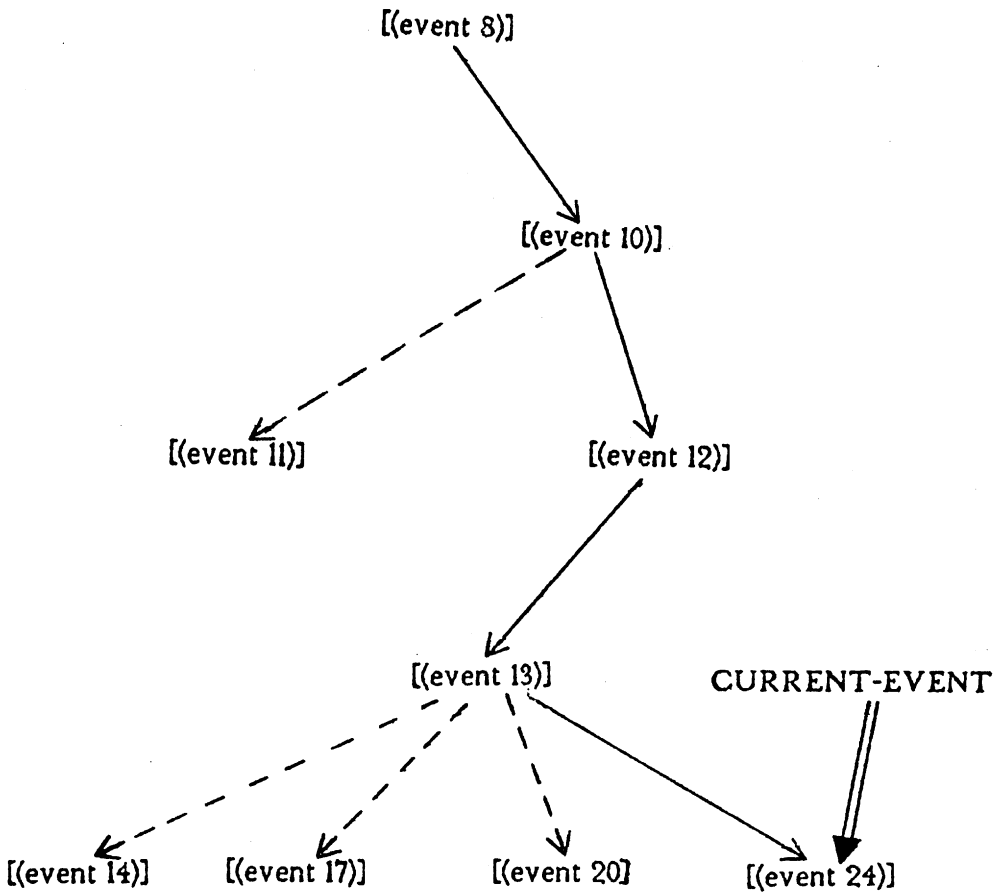
A Snapshot of the Event Tree

Figure 5.5a

```
[(event 20)
   calling-event%: (event 13)
   activity%: (determine (evaluation
                     (feasibility (system-component (handle (constraints joint-ordering))))))
   procedure%: ((determine (evaluation
                     (feasibility (system-component (handle (constraints joint-ordering))))))
                      (when (status (constraints joint-ordering) present)))
   selection-values%: (status ((constraints joint-ordering)
                              (((department purchasing) 1)((firm 1)(session 1)))) present)]

[(event 24)
   calling-event%: (event 13)
   activity%: (determine (evaluation
                     (type (system-component (handle (constraints joint-ordering))))))
   procedure%: ((determine (evaluation
                     (type (system-component (handle (constraints joint-ordering))))))
                      (when (status (constraints joint-ordering) present)))
   selection-values%: (status ((constraints joint-ordering)
                              (((department purchasing) 1)((firm 1)(session 1)))) present)
   continuation%: (method (determine (evaluation (type (system-component
                                    (handle (constraints joint-ordering)))))))]
```

Continuation of Figure 5.5a



The Relationship Between Events in the Snapshot

FIgure 5.5b

[(INVESTIGATE (SESSION A))]. The second pointer is CURRENT-EVENT which points to the event that is currently being executed.

The event tree is used primarily to sequence activities for execution. The activity to be executed next is always the first activity on the continuation of CURRENT-EVENT. Otherwise, if this continuation is empty, it is the first activity on the continuation of the calling event. The rule is applied recursively until PROCTOR reaches TOP-EVENT. PROCTOR simply returns to the top level loop when there is no next activity.

The event tree is pruned whenever the execution of an event is complete. Thus, the events linked by dotted lines in figure 5.5b do not exist when we execute [(EVENT 24)]. A saved event tree may have been useful, especially in the generation of explanations. We felt, however, that there was too large an overhead in saving the complete tree. This deficiency can be overcome: the tree is easily recreated by recomputing appropriate parts of the session.

Each node of the event tree may have additional attributes. Selection-values is an "instantiated" assertion concerning the value of type I facts that were used in the selection of a procedure for the activity. (See section 5.3.2.1 for a description of instantiation.) Selection-values are used in the determination of environments. An event may also have a dependency attribute that specifies the explicit environment for an activity.

5.3.2 The Entity Tree

Entities are object in the user's world. In the current implementation, entities and sets of entities can include sessions, a particular session, the firms of a session, a

particular firm of a session, the departments of a firm, the purchasing departments of a firm and a particular purchasing department. These are represented in OWL as

```
[SESSION]
[(SESSION 1)]
[(FIRM (SESSION 1))]
[((FIRM 1)(SESSION 1))]
[(DEPARTMENT ((FIRM 1)(SESSION 1)))]
[((DEPARTMENT PURCHASING)((FIRM 1)(SESSION 1)))]
[(((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))]
```

Figure 5.6 shows the structure of a set of entities for a hypothetical data base.

PROCTOR maintains a pointer (called CURRENT-ENTITY) to a node in this tree. CURRENT-ENTITY is the entity or set of entities that is currently under investigation.

A new entity can be created whenever PROCTOR executes an investigate entity activity. PROCTOR can be told to investigate an entity, to investigate the entity, to investigate another entity or to investigate a set of entities. Some examples are:

```
[(INVESTIGATE (FIRM A))]
[(INVESTIGATE (FIRM THE))]
[(INVESTIGATE (FIRM ANOTHER))]
[(INVESTIGATE (DEPARTMENT FIRM))].
```

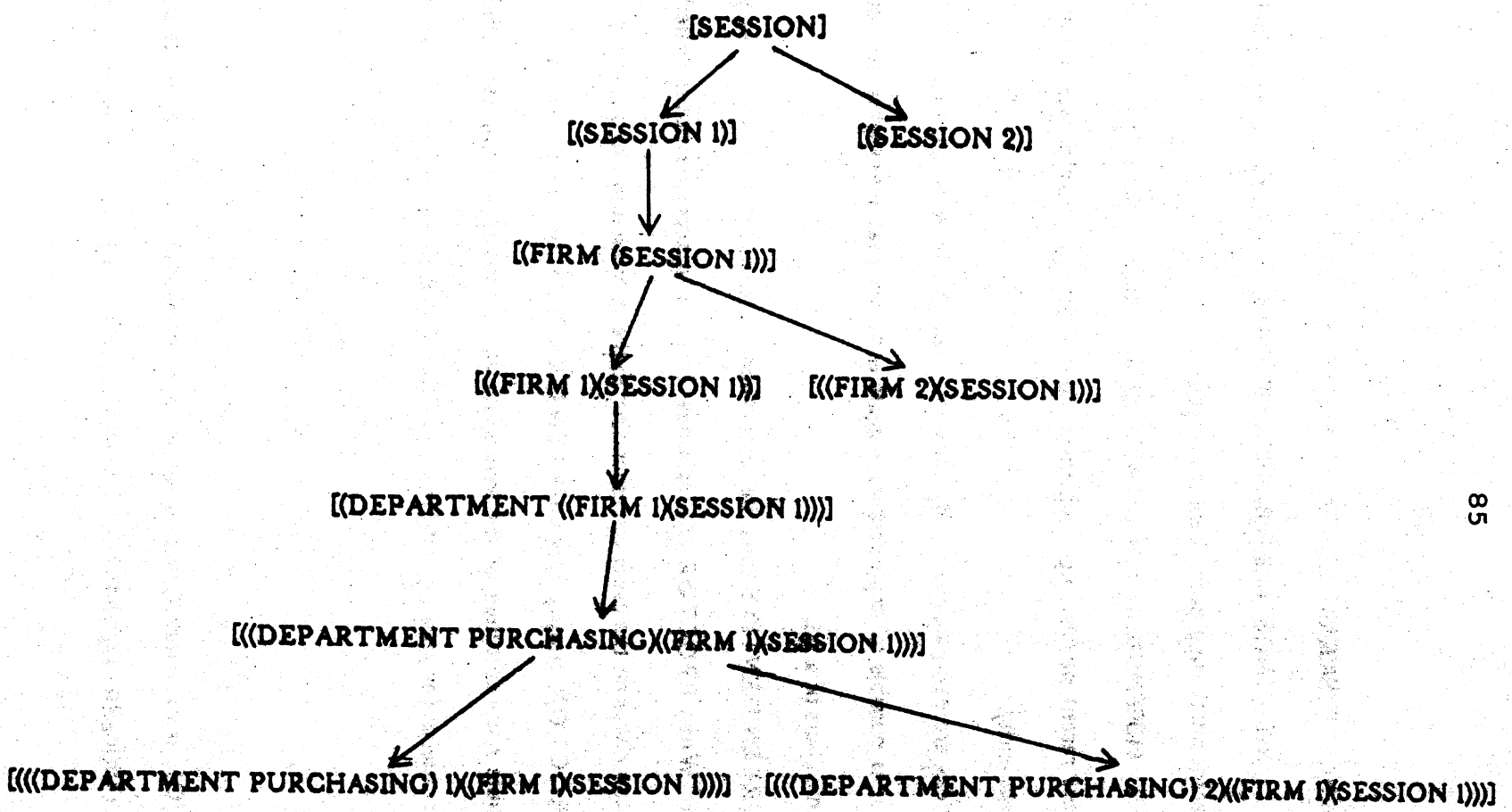
The new entity depends on both the CURRENT-ENTITY and the investigate activity. Consider figure 5.6. For a CURRENT-ENTITY of [((FIRM 1)(SESSION 1))] and an investigate activity of

```
[(INVESTIGATE ((DEPARTMENT PURCHASING) ANOTHER))],
```

the new current entity will be

```
[(((DEPARTMENT PURCHASING) 3)((FIRM 1)(SESSION 1)))].
```

CURRENT-ENTITY is set to



A Tree of Entities

Figure 5.6

[(((DEPARTMENT PURCHASING) 2)((FIRM 1)(SESSION 1)))]

when the activity [(INVESTIGATE ((DEPARTMENT PURCHASING) THE))] is executed. (We find the most recent purchasing department investigated.)

[(INVESTIGATE ((DEPARTMENT PURCHASING) A))] indicates that PROCTOR should find the most recent purchasing department investigated or else create a new purchasing department entity.

These ideas are easily extended. By specifying selectors such as all, each, first, second or previous, it is possible to implement investigate activities that investigate sets or that iterate through members of a set.

The CURRENT-ENTITY must be reset when an investigate entity activity completes execution. When PROCTOR creates a new entity, it places attributes called previous-entity and new-entity on the event corresponding to the execution of the investigate entity activity. PROCTOR simply sets CURRENT-ENTITY to the value of the previous-entity attribute once execution of the investigate entity activity is complete. The new-entity attribute is useful for resetting entities when PROCTOR travels down the event tree.

5.3.2.1 Instantiations

PROCTOR uses *instantiation* to relate facts to entities in the data base. Consider the fact [(NUMBER ((DEPARTMENT PURCHASING) FIRM))]. This fact is instantiated to

[(NUMBER ((DEPARTMENT PURCHASING)((FIRM 1)(SESSION 1))))]

when CURRENT-ENTITY is [((FIRM 1)(SESSION 1))]. The instantiation of

[(STATUS (CONSTRAINTS JOINT-ORDERING))] is

[(STATUS ((CONSTRAINTS JOINT-ORDERING)
((((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1))))))]

when CURRENT-ENTITY is

[(((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))].

The rules for instantiation are fairly straightforward. Let us define a *subentity* of an entity X as any entity that appears as a son of X in the entity tree. A *superentity* of an entity X is any entity that appears as a father of X in the entity tree. This implies that [SESSION] is the superentity of all entities.

The first example illustrates *explicit instantiation*. Concepts that contain

```
[SESSION]
[(FIRM SESSION)]
[FIRM]
[(DEPARTMENT FIRM)]
[((DEPARTMENT PURCHASING) FIRM)] or
[(DEPARTMENT PURCHASING)],
```

are instantiated (depending on CURRENT-ENTITY) to contain

```
[(SESSION 1)]
[(FIRM (SESSION 1))]
[((FIRM 1)(SESSION 1))]
[(DEPARTMENT ((FIRM 1)(SESSION 1)))]
[((DEPARTMENT PURCHASING) ((FIRM 1)(SESSION 1)))] or
[(((DEPARTMENT PURCHASING) 1) ((FIRM 1)(SESSION 1)))].
```

In making explicit instantiations, there are three cases: CURRENT-ENTITY can be a subentity of the class of entity that is required; it can be a superentity of the class of entity that is required; or it can be of the correct class. In each case, the entity is simply retrieved by searching the tree starting at CURRENT-ENTITY. It is an error if an entity of the correct class cannot be found.

The second instantiation example illustrates *default instantiation*. A concept may have a DERIVED-ENTITY descriptor on its reference list (or on the reference list of a generalizer). Such a concept is called a *derived entity*. ([VENDORS] and [ITEMS] are examples.) PROCTOR specializes a derived entity by CURRENT-ENTITY when there are no instantiations by either a subentity or superentity of CURRENT-ENTITY. Otherwise, PROCTOR uses the instantiation that already exists.

5.3.3 The Environment Tree

The value of a fact depends on the environment in which that value was determined. An environment is represented by the concept [ENVIRONMENT] specialized by a conjunction of instantiated assertions concerning the values of facts that are contained in the environment. Suppose, for example, that an environment contains the facts

```
[(ACTIVITY FIRM)] and
[(STATUS (CONSTRAINTS JOINT-ORDERING))],
```

that apply to the entities

```
[((FIRM 1)(SESSION 1))] and
[(((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))],
```

and whose values are [PURCHASING] and [PRESENT]. This environment is represented by

```
[(ENVIRONMENT
  (AND (ACTIVITY ((FIRM 1)(SESSION 1)) PURCHASING)
       (STATUS
            ((CONSTRAINTS JOINT-ORDERING)
              (((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1))))
            PRESENT)))]
```

Note that the grouping AND is represented in OWL as a concept which has an element property whose reference list contains the members of that grouping. In

PROCTOR, we use the concept [(((AND X) Y) Z)] to represent the grouping [(AND X Y Z)].

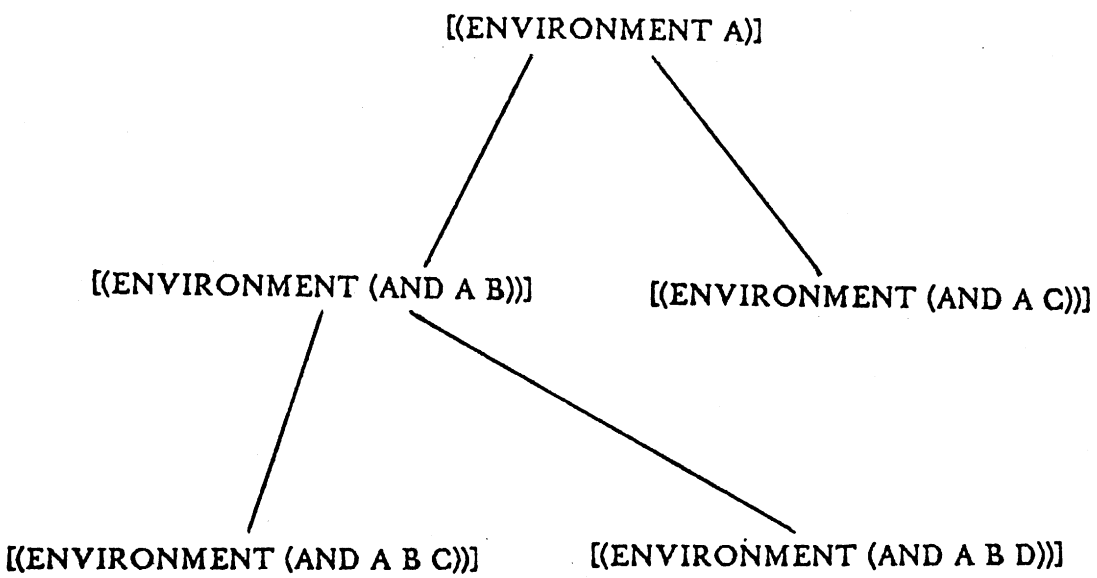
With this representation, OWL arranges environments into a tree. Suppose we had the environments,

```
[(ENVIRONMENT X)],
[(ENVIRONMENT (AND A B))],
[(ENVIRONMENT (AND A C))],
[(ENVIRONMENT (AND A B C))]
and [(ENVIRONMENT (AND A B D))].
```

The OWL data base permits us to traverse these environments as if they were structured as the tree in figure 5.7. We take advantage of this representation when determining the validity of environments in the change answers routine.

An environment is easily derived from the event tree: it is a conjunction of the selection-values attributes that appear on events in the path from CURRENT-EVENT to TOP-EVENT. An exception occurs when an event in this path has a dependency attribute. The environment for this case is a conjunction of the dependency attribute and all selection-value attributes that appear on events in the path from CURRENT-EVENT to the event with the first dependency attribute.

Each environment is given a value of TRUE, FALSE or TO-BE-CHANGED. A newly created environment always has a value of TRUE. An environment is given a TO-BE-CHANGED or FALSE value when the value of a type I fact in that environment is to be changed or when the value has changed.



A Tree of Environments

Figure 5.7

5.3.4 The Used-by Lattice

Chapter 4 discussed the notion of the direct dependency of a fact on the facts that enter into its determination. In the implementation, we record these dependencies by giving each fact a value-used-by attribute. The reference list of the value-used-by attribute of a fact holds all facts that have used the value of that fact.

The value-used-by attribute imposes a partial ordering on facts in the data base. Fact A comes before facts B in this ordering if and only if the value of fact A is used in the determination of fact B. In other words, fact B appears on the reference list of the value-used-by attribute of fact A. Notice that circularities cannot exist: there is no feedback in PROCTOR; a fact A cannot depend on a fact B which in turn depends on fact A.

The used-by lattice is easily maintained by means of a procedure called FIND-VALUE. FIND-VALUE places fact A in the value-used-by attribute of fact B if the value of fact B is referenced in the determination of fact A.

5.4 Back to Basics

5.4.1 Values

In previous sections, we described elements of how PROCTOR maintains values in the data base. We will summarize the description in this section.

PROCTOR maintains a distinction between values of facts and values of responses to questions. The concept for "value of the status of economies of transportation" for the entity [(((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))] is represented by the concept

```
[(VALUE (STATUS (ECONOMIES-OF-TRANSPORTATION
   (((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))].
```

The concept for "response to the question concerning the status of economies of transportation" and for the same entity is represented by

```
[(RESPONSE (ASK (STATUS (ECONOMIES-OF-TRANSPORTATION
   (((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))].
```

The first position of the reference list of each of these concepts contains a value that can be one of UNDETERMINED, UNKNOWN or some legal value. A value of a fact is UNDETERMINED if there has been no attempt to determine its value. It is UNKNOWN if the user specified a response of UNKNOWN or if PROCTOR can only assert a value of unknown due to lack of information.

Each instantiated fact/response concept has a value-used-by attribute, an environment attribute and a creating-activity attribute. The value-used-by attribute has been explained in section 5.3.4; the environment attribute contains the environment for the fact/response; the creating-activity attribute contains the activity that created the value. The creating-activity attribute provides quick access to the activity for the determination or asking of a fact.

The fact/response concept may also have a preliminary-value or preliminary-response attribute. These are unclassified attributes that are used by the change routine for temporarily setting the value of a fact/response to undetermined.

5.4.1.1 FIND-VALUE and SET-VALUE

FIND-VALUE and SET-VALUE are functions that maintain and provide access to values in the data base.

FIND-VALUE takes a concept as an argument, instantiates that concept and returns the value of that concept. The rule for FIND-VALUE is straightforward: if a preliminary-value/preliminary-response attribute exists, return its value; if no value exists, return UNDETERMINED; if a value exists but the environment has a value of FALSE or TO-BE-CHANGED, return UNDETERMINED; otherwise return the value. FIND-VALUE updates the value-used-by attribute only if the returned value is a legal non-preliminary value.

SET-VALUE takes a concept and a value as arguments, instantiates the concept and correctly set its value. SET-VALUE also "unsets" any preliminary-value, updates the creating-activity attribute, sets the environment and removes all references from the value-used-by attribute. SET-VALUE has another important effect: it recomputes all environments when it sets a value for a type I fact that has just been changed.

5.4.2 Evaluating Expressions

In PROCTOR, expressions occur as conditions on methods of determine and check activities, as conditions in prerequisites and when specializations, and as arguments of assertions in determine activities. The syntax for expressions is described by the BNF of figure 5.8.

Expressions are evaluated by recursively applying the rules of figure 5.9. Notice that an expression can evaluate to UNKNOWN or UNDETERMINED if data is UNKNOWN or UNDETERMINED. Notice also that BE is different from EQUAL. BE can compare a value to UNKNOWN without evaluating to UNKNOWN.

MINIMUM, MAXIMUM and AVERAGE are both unary and n-ary operators. The

condition ::= (IF predicate) | (UNLESS predicate) | OTHERWISE |
(WHEN predicate)

predicate ::= (AND predicate$_1$ predicate$_2$ . . . predicate$_n$) |
(OR predicate$_1$ predicate$_2$ . . . predicate$_n$) |
((BE value) fact) | (bop expression$_1$ expression$_2$) |
(NOT predicate) | TRUE | FALSE

expression ::= (bop expression$_1$ expression$_2$) | (uop expression) |
value | (nop expression$_1$ expression$_2$ . . . expression$_n$) |
fact

bop ::= GREATER-THAN | LESS-THAN | EQUAL

bop ::= QUOTIENT | DIFFERENCE

nop ::= TIMES | PLUS | MAXIMUM | MINIMUM | AVERAGE

uop ::= MAXIMUM | MINIMUM | AVERAGE | MINUS

value ::= integer | floating point number | range number | 'symbol

fact ::= an instantiated value fact | an instantiated response fact

BNF for Expressions in PROCTOR

Figure 5.8

When x and y represent values of facts or constants,
[(AND x y)] evaluates to
[TRUE] if x = [TRUE] ∧ y = [TRUE],
[FALSE] if x = [FALSE] ∨ y = [FALSE],
[UNDETERMINED] if (x = [UNDETERMINED] ∧ y ≠ [FALSE]) ∨
(x ≠ [FALSE] ∧ y = [UNDETERMINED]),
[UNKNOWN] if (x = [UNKNOWN] ∧ y ≠ [FALSE] ∧ y ≠ [UNDETERMINED]) ∨
(x ≠ [FALSE] ∧ x ≠ [UNDETERMINED] ∧ y = [UNKNOWN]).

[(OR x y)] evaluates to
[TRUE] if x = [TRUE] ∨ y = [TRUE],
[FALSE] if x = [FALSE] ∧ y = [FALSE],
[UNDETERMINED] if (x = [UNDETERMINED] ∧ y ≠ [TRUE]) ∨
(x ≠ [TRUE] ∧ y = [UNDETERMINED]),
[UNKNOWN] if (x = [UNKNOWN] ∧ y ≠ [TRUE] ∧ y ≠ [UNDETERMINED]) ∨
(x ≠ [TRUE] ∧ x ≠ [UNDETERMINED] ∧ y = [UNKNOWN]).

[(IF x)] evaluates to x.
[(WHEN x)] evaluates to x.

[(UNLESS x)] evaluates to [(NOT x)].
[(NOT x)] evaluates to
[TRUE] if x = [FALSE],
[FALSE] if x = [TRUE],
[UNKNOWN] if x = [UNKNOWN],
[UNDETERMINED] if x = [UNDETERMINED].

When op = bop | bcp | nop,
[(op x y)] is
[UNDETERMINED] if x = [UNDETERMINED] ∨ y = [UNDETERMINED],
[UNKNOWN] if (x = [UNKNOWN] ∧ y ≠ [UNDETERMINED]) ∨
(x ≠ [UNDETERMINED] ∧ y = [UNKNOWN]),
op(x,y) otherwise.

[((BE x) y)] is
[UNDETERMINED] if x = [UNDETERMINED] ∨ y = [UNDETERMINED],
x = y otherwise.

[(uop x)] is
[UNDETERMINED] if x = [UNDETERMINED],
[UNKNOWN] if x = [UNKNOWN],
uop(x) otherwise.

Rules for Evaluating Expressions in PROCTOR

Figure 5.9

unary version applies only to *range quantities* which are values such as [<11], [24-58] and [>100]. These range quantities are represented by the concepts

```
[(QUANTITY (LESS-THAN 11))]
[(QUANTITY (BETWEEN (AND 24 58)))]
[(QUANTITY (GREATER-THAN 100))]
```

The maximum of [<11] is 10, of [24-58] is 58 and of [>100] is 200. PROCTOR assumes a bound of twice the lower bound for "greater-than" ranges. The minimum of [>100] is 101, of [24-58] is 24 and of [<11] is 0. Notice that quantities in ranges are never negative. The average of a range is simply the average of the maximum and minimum of that range.

5.5 Executing a Selected Procedure

PROCTOR uses special interpreters to execute procedures for each type of activity. These are described in the following sections.

5.5.1 The Ask Interpreter

The following are examples of ask activities:

```
[(ASK STATUS)
  [RESPONSE:
    TYPE:: YES-NO
    (TRANSLATION:: ABSENT PRESENT)]]

(TEXT [(ASK (STATUS ECONOMIES-OF-TRANSPORTATION))]
"(ARE THERE ECONOMIES OF TRANSPORTATION WHEN YOU ORDER
ITEMS FROM A GIVEN VENDOR  I.E. WOULD IT BE BETTER TO ORDER
ITEMS IN TRUCK LOADS, OR CAR LOADS WHENEVER AN ORDER IS PLACED?))

(TEXT [(ASK (NUMBER FAMILIES))
          [RESPONSE:
            TYPE:: SINGLE-CHOICE
            (OPTIONS:: <11 11-50 51-100 101-250 251-500 >500)]]
"(HOW MANY FAMILIES OR GROUPS OF ITEMS ARE THERE?))
```

Each ask procedure has a response attribute which forms the basis of its method. A response is described by a type attribute (description, yes-no, yes-no-value, single-choice, multiple-choice or value), a text attribute, and depending on the type, a syntax attribute, an options attribute and a translation attribute. The text attribute is created by the TEXT function which converts a list of text into an internal representation. (See section 5.7.) Syntax, translation and options are defined as groupings. Syntax is an ordered list of predicates that are applied to a response to insure its syntactic correctness. Translation is an ordered list of values that are used to translate a yes-no or choice response. Options are

printed at the terminal for single and multiple choice responses. The options attribute can replace a translation attribute when a translation field is absent.

We make use of OWL's ability to inherit properties when defining ask activities. [(ASK (STATUS ECONOMIES-OF-TRANSPORTATION))], for example, will borrow its type and translation attribute from [(ASK STATUS)]. In general, missing attributes can be inherited from any generalization of a response.

The ask interpreter checks the consistency of a syntactically correct and translated response by calling the check interpreter. It eventually asserts the response by using SET-VALUE which correctly instantiates the fact and updates its environment.

The ask interpreter records the question number that is assigned to a question. Each instantiated response concept has a question-number attribute on its reference list. There is also a [(QUESTION n)] concept which contains the instantiated response concept on its reference list. The ask interpreter is intelligent enough to know that a new question number should not be assigned to a previously asked question. It will not ask a question if the previous response to that question is still valid.

5.5.2 The Investigate Interpreter

A procedure for an investigate activity is an ordered list of determine, consider, explain and investigate activities. (See section 5.2 for an example). The investigate interpreter simply pushes the activities of its method on the continuation of the current event (in reverse order of course). PROCTOR executes these activities when it continues its cycle.

5.5.3 The Consider Interpreter

A consider activity is a restricted version of an investigate activity. PROCTOR uses a common interpreter to execute both consider and investigate activities.

5.5.4 The Determine Interpreter

The following is an example of a determine activity:

```
[(DETERMINE (STATUS LONG-LEAD-TIME-ITEMS))
 [METHOD:
  [STEP::1
     (ASSERT 'PRESENT)
     (IF [OR: (RESPONSE (ASK (STATUS LONG-LEAD-TIME-ITEMS))
                 PRESENT)
              (STATUS IMPORTED-ITEMS PRESENT)])]
  [STEP::2 (ASSERT 'ABSENT)
     (IF [AND: (RESPONSE (ASK (STATUS LONG-LEAD-TIME-ITEMS))
                 ABSENT)
              (STATUS IMPORTED-ITEMS ABSENT)])]
  [STEP::3 (ASSERT 'UNKNOWN) OTHERWISE]]]
```

The procedure for a determine activity can have one or more *methods*. These are executed sequentially until a method succeeds in asserting a value. (This is much like a LISP COND.) It is an error if no method succeeds.

Each method may have one or more *steps* defined for it. A single step method may omit the step in its representation. Each step is conditioned by an optional logical expression: [(IF condition)], [(UNLESS condition)] or OTHERWISE. OTHERWISE must occur in the last step of a method and succeeds only if all other steps fail. A step is executed only if its condition is satisfied: this implies that more than one step can be executed during the execution of a method.

Each step may have an activity and zero or more *then continuations* which contain additional activities to be executed as part of a step. The activities of a determine are ask, determine, explain, say, comment and assert activities. Say simply prints text at the terminal; comment prints text at the terminal and stores the text with the fact for printing when the data base is dumped; assert asserts a value for the fact being determined.

The determine interpreter makes full use of PROCTOR and the event tree when it executes a procedure.

The determine interpreter first checks the current value of the fact to insure that it is invalid. It immediately returns to PROCTOR if a valid value exists. Otherwise, the determine interpreter places each of the methods of the determine procedure on the continuation of the event for the determine activity and returns to PROCTOR.

PROCTOR recognizes that methods are continuations of a determine activity and calls the continue-determine interpreter to complete the execution of the determine. The continue-determine interpreter places all steps of a method in the continuation of CURRENT-EVENT (the event for the execution of the method). Continue-determine will similarily place the condition and activities of a step in the continuation of the event for the execution of that step.

The continue-determine interpreter can evaluate expressions and modify the event tree. It removes all continuations from the event for a step if the condition for that step fails. The continue-determine interpreter will remove all continuations from the event for the determine activity when a method for that activity succeeds in asserting a value.

In evaluating an expression, it is possible that certain facts will be undetermined. Continue-determine delays the evaluation of such an expression by placing determine

activities for each undetermined fact on the continuation in front of the expression. The expression is eventually evaluated with correctly determined facts.

With this approach to interpreting determine activities, the execution of a determine can be interrupted both to determine undetermined facts/responses and to return to toplevel mode.

5.5.5 The Explain Interpreter

The explain interpreter is trivially implemented in PROCTOR. The explain procedure method contains a prompter and text attribute. The prompter is optional; it asks if the user wishes to see an explanation. The text attribute contains the text of the explanation.

Explain concepts are loaded by an explanation function. The following is a typical example:

```
(EXPLANATION
  [(EXPLAIN (DIFFERENCE (BETWEEN (AND DEMANDS SALES))))]
    '(. . . the prompter for the explanation . . .)
    '(. . . the text of the explanation . . .))
```

5.5.6 The Check Interpreter

The check activity has a representation that is similar to that of a determine activity. The difference is that a check activity may have nested steps in its method. The following is an example:

```
[(CHECK (AND (RESPONSE (ASK (STATUS (ITEMS SEASONAL))))
             (RESPONSE (ASK (STATUS SEASONAL-INVENTORIES)))))
  [METHOD:
    [STEP::1
        (SAY ""SEASONAL INVENTORIES CANNOT BE PRESENT
             IN THE ABSENCE OF SEASONAL ITEMS.")
        (IF (AND:::  (RESPONSE (ASK (STATUS (ITEMS SEASONAL))) ABSENT)
             (RESPONSE (ASK (STATUS SEASONAL-INVENTORIES)) PRESENT))))]
    [STEP::2
        (SAY ""YOU MUST HAVE SEASONAL INVENTORIES IF YOU HAVE
                  SEASONAL ITEMS.")
        (IF (AND:::  (RESPONSE (ASK (STATUS (ITEMS SEASONAL))) PRESENT)
             (RESPONSE (ASK (STATUS SEASONAL-INVENTORIES)) ABSENT))))]]
```

The check interpreter is called by the ask interpreter when the response to a question must be verified to be consistent and semantically correct. The check interpreter first retrieves all check activities for a response: there can be any number of activities to check a response against other responses. It then executes only those activities that have all responses determined. Note that check does not try to determine undetermined information.

Check makes no use of PROCTOR in interpreting its method. It merely evaluates the conditions of the steps until it either completes a method or until it reaches the deepest step. When check reaches an inner step, it has detected an error. Check then either uses the condition on that step to generate an explanation to the user or else it uses a text segment to print an explanation for the user.

There are two methods of recovery for a check error. The current question may simply be reasked, or the user may request that one or more of the facts that appear in the definition of the check be reasked. Check returns control to the ask interpreter if the current response is the only response to be changed. Otherwise, it executes the remaining check activities and eventually passes control to the change answers routine.

5.6 The Change Routine

There are three components to the procedure for changing answers: the user is first asked to specify the responses he wishes to change; these responses are exploded to find all facts that are directly affected by the changes; a type 1 or type 2 change procedure is then executed.

5.6.1 Accepting Change Requests from the User

The user specifies answers to be changed by stating the question numbers for these responses. PROCTOR converts these numbers into the equivalent instantiated response concepts. The user can specify changes in any order; he may interrupt the change routine at any time. Note, however, that he may not continue the analysis until all changes have been processed. PROCTOR can forget changes if requested by the user. Here, the preliminary-value/preliminary-response attributes become important. In processing a change, PROCTOR simply sets a preliminary response to undetermined; it does not change the actual value of a response. PROCTOR is thus able to "unset" any change upon request.

5.6.2 Exploding the Direct Dependencies

PROCTOR uses a queue to find all facts that are directly affected by the requested changes. The requested changes are first placed in this queue. PROCTOR then processes each element of the queue by inspecting the next fact in the queue, checking to see if it has been processed and if not, by placing all unprocessed facts on the value-used-by attribute of that fact at the end of the queue. The process eventually terminates. PROCTOR sets the preliminary value of each processed fact to undetermined.

A problem arises when incomplete determine activities have referenced facts that are to be changed. (The user can interrupt a question and hence the determination of a fact. These partially determined facts may have used the values of facts that are to be changed.) PROCTOR is careful not to include incompletely determined facts in the explosions. The type 1 and type 2 routines take appropriate action to handle incomplete determine activities.

In exploding the changes, PROCTOR must determine if any type 1 facts have been affected by the change. (Type 1 and type 2 facts are distinguished by descriptors on their reference list or on the reference list of one of their generalizations.) PROCTOR will execute the type 1 change routine if one or more type 1 facts have been affected. Otherwise, it uses the type 2 routine.

5.6.3 The Type 1 Change Procedure

The type 1 change procedure is conceptually very simple. The values of all environments are first recomputed. This is easily done by taking advantage of the tree-like structure of the environment concepts. Each environment with an undetermined fact is given a value of TO-BE-CHANGED. The change routine then erases the current state of the

event tree and sets the continuation of TOP-EVENT to contain the activity [(INVESTIGATE (FIRM THE))].

As PROCTOR recomputes the session, it recomputes the values of all facts that are undetermined. In recomputing, it may determine new facts. SET-VALUE resets environments as facts and responses are redetermined. Notice that with this scheme, all facts that were invalidated by a change in an environment can automatically be made valid if a type 1 fact is reset to its original value.

5.6.4 The Type 2 Change Procedure

The type 2 change procedure does not force a review of the entire session. This routine simply alters the event tree so that changed type 2 facts may be reevaluated. The change procedure first does a topological sort of all exploded type 2 facts. <Knuth 68> (The used-by lattice provides the comparison criteria for sorting these facts.) The order of the facts in the sorted output specifies the order for the redetermination of the changed type 2 facts.

The change routine creates a new event for each fact that is to be redetermined and makes these events the sons of TOP-EVENT. It sets the attributes of these events so that PROCTOR can correctly simulate the original execution. The activity attribute is obtained from the creating-activity attribute of the instantiated fact; the selection-value attribute is set to the environment attribute of the fact; the procedure for the activity is obtained by calling the procedure selection routine. (Remember that type 1 facts have not been changed. PROCTOR will therefore select the procedure that was used in the previous determination.) A current entity can be easily obtained from the instantiated fact. The

procedure sets new-entity and previous entity attributes appropriately.

PROCTOR places first CURRENT-EVENT and then the newly created events on the continuation of TOP-EVENT and sets CURRENT-EVENT to TOP-EVENT. When PROCTOR executes, it recognizes events on continuations and is able to bypass the procedure selection routine. PROCTOR will "execute" each of the events and hence, redetermine their values. Notice that all facts are redetermined in their original environment. PROCTOR continues normal execution at the deepest node of the event tree once all changes have been processed.

We have mentioned that interrupted determine activities pose a problem. The change routine erases the events for these activities and resets the continuations of their calling events before it processes the changes. These determines are subsequently correctly restarted.

5.7 Printing English

PROCTOR prints English from prestored text and by generating simple sentences from OWL concept structure. Text is stored as either LISP-TEXT or OWL-TEXT. The specializer of a LISP-TEXT concept is an index to an array that contains stored lists of text. (This array is loaded by the TEXT and EXPLANATION functions.) The specializer of OWL-TEXT is an OWL symbol (a string) that can be easily printed at the terminal. OWL-TEXT appears in say and comment activities.

5.7.1 Generating English

PROCTOR uses mutually recursive "generation experts" to convert concepts to text. Each class of concept has, on its reference list or on the reference list of one of its generalizations, a descriptor that names the appropriate expert to be used in English generation.

PROCTOR has experts to handle concepts such as groupings, BE predicates, PROPERTY concepts, EVALUATION concepts and others. The BE expert will convert

```
[((BE PRESENT)
    (STATUS ((CONSTRAINTS EXTERNAL)
        (((DEPARTMENT PURCHASING) 1)((FIRM 1)(SESSION 1)))))))]
```

to "There are external constraints in the purchasing department". It passes the concept to the BE-STATUS expert who outputs "There are" since the value of the status is PRESENT and since [(CONSTRAINTS EXTERNAL)] is plural. ([CONSTRAINTS] has a [PLURAL] descriptor on its reference list.) The BE-STATUS expert passes

```
[(STATUS ((CONSTRAINTS EXTERNAL)
        ((DEPARTMENT PURCHASING)((FIRM 1)(SESSION 1))))))]
```

to the STATUS expert who prints "external constraints in the purchasing department". The STATUS expert uses the ENTITY expert to correctly identify the purchasing department entity. (The purchasing department may have a name that should be printed instead.)

A concept can have a descriptor of class PRINT-SYMBOL on its reference list. The specializer of this descriptor is an OWL symbol that can override the general print mechanism for that concept.

5.7.2 Generating Reasons and Evaluations

PROCTOR generates statements and reasons for each evaluation that it makes. The reason for an evaluation is simply the condition of the step that asserted the evaluation. Or, if this condition is absent, it is the selection value for the determine procedure. Evaluations are elaborated by using say and comment activities.

PROCTOR takes advantage of the entity tree structure when it generates dumps of the problem and the associated evaluations. As it traverses the tree in a breadth-first manner, PROCTOR lists all relevant information for each entity encountered. This simple mechanism gives PROCTOR the ability to create "semi-organized" dumps of the data base.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The growing need for experts in areas such as law, medicine and management has motivated research in expert systems <Gorry 74>. There are programs that are expert in legal issues such as the distinction between assault and battery cases <Meldman 75>, programs that can prescribe medicines for various bacterial infections <Shortliffe 74>, and systems that can automatically generate data processing software <Ruth 75>. These programs are designed as tools assist to experts and non-experts in the solution of problems for specific domains. They are meant to supplement expertise rather than to replace it.

The success of these systems motivated us to tackle a problem in Operations Management. It was first necessary to select a subdomain of managable size before any reasonable attempt could be made. The domain of Operations Management was pruned to the subdomain of procurement, and this in turn was pruned to the area of planning and control systems for procurement. From the variety of possible methodologies, we chose a specific approach: the hierarchical approach for planning and control advocated by Hax and Meal. Our research lead to the development of PROCTOR, an expert in hierarchical planning and control systems. PROCTOR does not replace the system analyst or manager; it assists the analyst by providing him with a formalism for exploring issues relevant to the design of a hierarchical planning and control system for procurement.

6.1 Relation to Other Work

Since much of our work has been influenced by research in expert systems, it is interesting to relate PROCTOR to current research with respect to both computer science and management issues.

There are similarities between PROCTOR and medical expert programs such as MYCIN, a program that prescribes medicine for bacterial infections <Shortliffe 74>, and the Digitalis Therapy Advisor, a program that can suggest appropriate doses of digitalis for treatment of heart conditions. <Silverman 74>

MYCIN is rule based. It starts with a goal (identify an infection and prescribe a medicine) and applies rules until it finds a solution. These rules are categorized into groups according how they satisfy prerequisites for the application of other rules. MYCIN selects rules by searching a Planner-like goal tree to find a rule that can derive information with minimal user questionning.

This control structure is similar to PROCTOR's but only at the level of determine activities. PROCTOR has rules (when specializations) for determining facts concerning the firm. PROCTOR differs from MYCIN in that PROCTOR's rules are much more structured and that only one rule is appropriate in any determination. (MYCIN might have several acceptable alternatives at any point in the analysis.) PROCTOR also differs in overall organization. PROCTOR follows a plan when investigating the firm while MYCIN is entirely ruled-based. PROCTOR strays from this plan only when it needs undetermined information; PROCTOR always returns to the plan.

In this respect, PROCTOR bears a certain similarity to the Digitalis Therapy Advisor. The Digitalis Therapy Advisor is controlled by a Therapy Transition Network

(TTNET). Each node of the TTNET has subgoals to be satisfied, and in satisfying these goals, the program exhibits its behavior. Nodes are arranged according to priorities that depend on the information known to the program. The system selects nodes according to these priorities to determine what it must do next. PROCTOR's activities are structured in a manner that is similar to the TTNET. The continuations of the event tree are subgoals that must be executed for PROCTOR to proceed. In selecting the goals, PROCTOR uses the priorities that are implicit in the ordering of nodes on the continuation.

Our work can be related to current research in management expert systems. The Automatic Programming Group at the Laboratory for Computer Science (formerly Project MAC) at MIT has been developing an automatic programming system called Protosystem <Ruth 75>. From a high level specification of requirements for a data processing system, Protosystem can generate a PL1 data processing program and the JCL necessary to run that program on an IBM machine. Protosystem requires an application expert, an interface between the problem domain and the program generator. This expert could assist a user in determining his requirements and thus in writing specifications for Protosystem. PROCTOR may be suited to this application. It assists the user in defining his requirements by evaluating components for an applications system. PROCTOR's output could drive a more detailed questionnaire that resolves issues of implementation and that determines the user's requirements in terms of data handling capability and report generation.

Some work has recently been done in providing computers with natural language understanding. This research, though not directly related to PROCTOR, is very important for PROCTOR-like systems. A deficiency of PROCTOR is its lack of an

explanation capability. PROCTOR can dump a data base to provide a semi-organized description of the problem and its evaluations, but it cannot accept questions from the user and relate its evaluations to the user's model of the world. Malhotra has done experimental work in defining the requirements for an English interface to a management expert system. <Malhotra 75> He has classified the kinds of questions that managers ask and has stated the requirements for a system to answer these questions. Research has also been done in providing a computer with models for management problem solving. <Krumland 79> Krumland's system uses small generalizable models to solve problems presented in a dialogue with the manager. The issues of representation for the models and the dialogue are important for providing a management system with an explanation capability.

A project that is similar in goals but different in approach is Mark's reformulation model of expertise. <Mark 76> Mark's program accepts an English description of a simple inventory problem and tries to solve that problem by understanding it in terms of a model based on a theory of consulting. PROCTOR differs from Mark's system in that PROCTOR handles a much larger problem area but not at the same level of understanding. Mark gives his system a deep understanding of a small well-defined problem domain: his system solves small problems and solves them very well.

6.2 Further Research

This thesis has only begun to explore the issues relevant to an implementation of an expert for a subdomain of Operations Management. PROCTOR can be extended in a variety of directions both in the short and the long term.

6.2.1 Short Term Research Areas

Research must be done in extending PROCTOR's data base: areas of the data base are incomplete; many of our evaluations are superficial. (It is encouraging that PROCTOR can display acceptable interactions with even a partially complete data base.) The data base must eventually be tested "in the field" to insure its accuracy with respect to both methodology and the way experts actually analyze problems.

In implementing PROCTOR, we did not make full use of the OWL formalism. In generating English, for example, we did not make use of current ideas in English representation in OWL. Bill Swartout is currently implementing the Digitalis Therapy Advisor in the OWL interpreter. <Swartout 76> He hopes to provide the Digitalis Therapy Advisor with good explanation capabilities by taking full advantage of the OWL formalism. A similar project for PROCTOR might prove interesting.

PROCTOR lacks a well-developed notion of time. It knows that fact A came before fact B if B depends on A but it does not know when fact A was determined. It would be interesting to consider how time would improve the efficiency of the change routines. In changing type 1 answers, PROCTOR currently reviews the session from the beginning to determine what information needs to be changed. With a notion of time, it might not have to review investigations into joint ordering interactions when, for example, the status of vendor tradeoffs has been changed.

6.2.2 Long Term Research Areas

There is no limit to research in extending the usefulness of a PROCTOR-like system.

PROCTOR could assess the cost-benefits of implementing a planning and control system for procurement. A manager, for example, often needs answers to questions like "What if I don't include this feature?" or "How much does lead time forecasting buy me and how much will it cost?". Research is required in defining methods for making such analyses.

Related to research in costs benefits analyses is the need to continue research in Operations Management methodology. Operations management techniques must be better formalized before a system can hope to provide expert evaluations.

PROCTOR could eventually be linked to an automatic programming system like Protosystem. PROCTOR could provide a first cut at a feasibility analysis; cost benefits experts could evaluate the impact at the Operations Management level of selecting different configurations; automatic programming experts could tackle issues related to data and report requirements. These experts could interact in the design and implementation of a planning and control system.

6.3 Conclusions

In this thesis, we have explored a subdomain of Operations Management. We implemented a program that assists the manager in exploring the issues that are relevant to an evaluation of the applicability of a hierarchical planning and control system for procurement. This thesis shows that such a system is feasible for the domain of

procurement.

The ideas of this thesis can probably be applied to the more general domain of production and inventory control systems. Whether our results are can be applied to other domains is an open issue. The applicability to non-Operations Management domains of ideas such as the categorization of facts for changing answers, the environment tree and the notion of direct dependencies certainly merits further exploration.

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APPENDIX A

SAMPLE SESSIONS WITH PROCTOR

This appendix contains several annotated sessions with PROCTOR. The sessions are complete except for minor editing to decrease the overall size of this appendix.

Introductory material....

Today is April 27, 1976.
The time is 7:25 pm.

What is your full name?
(Please enter your name followed by a return)
(Enter here): Mr. Adam Smith

And what do your friends call you?
(Please enter your name followed by a return)
(Enter here): Mr. Smith

Thank you Mr. Smith.

This questionnaire is designed to help you identify the general characteristics of a planning and control system to support decisions in the area of procurement.

Do you need information concerning the operation of this questionnaire?
Please follow your answer with a return.
(Please key in yes or no): yes

This is a short note concerning the use of the questionnaire.

The questionnaire has two modes of operation: analysis mode and toplevel mode. In analysis mode, we investigate your firm. In toplevel mode (which we are in now), you can request changes to your responses and listings of useful information. During the investigation, we will move freely between toplevel mode and analysis mode.

When you type in a response, follow it with a carriage return. If a question is multiple choice, enter your choices separated by blanks and follow these with a carriage return. If a question requires lines of text as input, follow each line of text with a carriage return and when finished enter an additional carriage return.

If you are uncertain about a response, key in ?. If you do this during the analysis of your firm, the questionnaire will try to proceed without the information. At toplevel, you will normally get an explanation.

You may interrupt analysis mode at any time by entering). This will take you to toplevel. Key in ?? to have the current question repeated. If you need this information again, just key in help as the response to any question.

Ok, let's begin.
And Mr. Smith, you are at top level. Please select one of the following:

1 quit

2 start an analysis
3 help

(Enter here): 2

(1) Mr. Smith, what is the name of your firm? Use as many lines as you need, following each line with a carriage return (cr). Finish by hitting an extra (cr). If you have no answer, just hit (cr). Please begin ...
KBS Foods Ltd

(2) What is the address of KBS Foods Ltd? Use as many lines as you need, following each line with a carriage return (cr). Finish by hitting an extra (cr). If you have no answer, just hit (cr). Please begin ...
Cambridge MA 02146

Now would you like an explanation of the elements of a general product structure that can be used to define the major activities of KBS Foods Ltd?
(Please key in yes or no): yes

One of the basic issues that determines the general characteristics of a planning and control system to support decisions in the area of purchasing and production management is the nature of the product structure of the firm.

An illustration of a fairly general product structure can be represented as follows:

suppliers

raw materials tools supplies maintenance parts purchasing

raw material inventory

component parts
-purchased parts
-fabricated parts production

parts work-in-process inventory (intermittent
-purchased subassemblies and
-fabricated subassemblies continuous
operations)

subassembly work-in-process
inventory

finished products
-purchased finished products
-manufactured products

finished product inventory

distribution process
-distribution centers distribution
-warehouses
-wholesalers

-retailers

The various elements of the product structure define three major functions: purchasing, production, and distribution.

Obviously not every firm possesses every element of the general product structure presented above. Retail or wholesale firms are engaged in purchasing activities alone. Many production plants are not involved in distribution operations.

As noticed in the above product structure, the production function (which transforms raw materials into finished products) can encompass two major types of operation: intermittent and continuous. It is useful to distinguish between intermittent and continuous activities since the manufacturing characteristics and the managerial decisions associated with these two processes are quite different. the following table provides a gross comparison between these two types of operations.

	type of process	
characteristics	intermittent	continuous
process configuration	job shop	assembly line
locus of decision making	decentralized	centralized
equipment	flexible	specialized
labor	high skilled	low skilled
scheduling	dispatching	permanent design

The following questions classify KBS Foods according to its activities, overall organization and size. The current version of PROCTOR can only handle a pure procurement firm with one department and "many" items. PROCTOR will let Mr. Smith proceed only if KBS satisfies this description.

(3) Mr. Smith, is KBS Foods Ltd a procurement firm with no distribution or production activities?
(Please key in yes or no): yes

(4) How many purchasing departments does KBS Foods Ltd have?
(Please key in a value): 1

(5) Does your purchasing department handle more than a few (say 10) items?
(Please key in yes or no): yes

PROCTOR first investigates joint ordering interactions and external constraints for items of KBS Foods Ltd.

PROCTOR offers a "canned" explanation concerning issues of aggregation since Mr. Smith requests it.

When dealing with purchasing decisions it is sometimes useful to aggregate individual items into groups of items for planning purposes. There are three categories of item aggregation: items, families, and product types.

Do you need information with regard to the definition of these three categories?
(Please key in yes or no): yes

The following three categories of item aggregation will be used:

Items refer to the highest degree of specificity regarding purchased products. Items differ in terms of packaging characteristics, size, color, dimensions, etc.

Families of items are groups of items that should be ordered jointly to obtain economies of scale or to facilitate the order release process. Items sharing a common ordering cost should be grouped in a family.

Product types constitute aggregation of items and families of items that share similar characteristics, such as similar demand patterns, unit costs, inventory holding costs, and lead times.

The start of the investigations into joint ordering interactions.

And Mr. Smith, we will now attempt to identify whether there are interactions among your purchased items that warrant aggregation of items into families.

Do you need information with regard to item interaction?
(Please key in yes or no): yes

Whenever there are no interactions among the purchased items, the control procedures are extremely simple. It is enough to project the requirements of each individual item during the procurement lead time, and to replenish the items inventory in appropriate economic quantities.

The most common interaction among purchased items is the joint ordering of several items from a single vendor. Advantages associated with joint ordering are lower freight rates, quantity discounts, allocation of the ordering cost among many items, and aggregate control of the various items. Disadvantages of joint ordering are increase in safety stocks, more complex control procedures, and less control on individual item service. Items that participate in joint ordering that share similar unit costs, demand patterns, and purchasing lead times are grouped into families for control purposes.

Questions 6 through 10 investigate the existence of interactions that warrant the consideration of a module to handle joint ordering interactions.

(6) Are there economies of transportation when you order items from a given vendor (e.g. would it be better to order items in truck loads, or car loads whenever an order is placed)?
(Please key in yes or no): n

Notice that when Mr. Smith is unable to answer question 7, PROCTOR offers an explanation and then explores complex orders and multi-item orders which indicate sources of common ordering costs. PROCTOR uses information from questions 8 and 9 when it explores KES's order characteristics later in the session.

(7) Are there economies of scale that can be obtained from joint ordering of several items because they will share a common ordering cost?
(Please key in yes or no): ?

Do you need information with regard to the components of the cost associated with issuing a purchasing order?
(Please key in yes or no): y

The purchasing ordering cost has two basic components.

The first component is the direct cost involved in releasing an order. It is represented by the cost of the order forms, envelopes, checks, receiving forms, stamps, some portion of the supplies of the purchasing department, as well as expediting materials, telex, and telephones.

The second component is represented by the salary of the personnel assigned to processing the order from its initial release to its final delivery. The following departments can be involved in the release of a purchasing order: purchasing, receiving and inspection, storage and warehousing, freight and traffic, accounts payable, machine accounting.

Occasionally, when dealing with very complex vendor orders containing multiple items, it is important to distinguish between a cost per header, which is the major ordering cost (a fixed unit shared by all the items in the order), and a cost per line which is a minor cost added to each line item.

(8) Do you have complex vendor orders containing multiple items where costs per header and costs per line items have to be identified?
(Please key in yes or no): n

(9) Now Mr. Smith, is it common for you to order more than one item in a given purchase order?
(Please key in yes or no): yes

(10) Are there quantity discounts that can be obtained by joint ordering of several items from a given vendor?
(Please key in yes or no): ?

PROCTOR has identified at least one joint ordering interaction: common ordering costs in question 9. Notice that it can proceed even with an unknown response for question 10.

Joint ordering support is possible if items can be grouped into families for joint replenishment.
(11) Are there groups of items (families) involved in joint ordering interactions that share similar unit costs, demand patterns purchasing lead times?
(Please key in yes or no): yes

Joint ordering support is necessary when a significant number of items are affected by these interactions
(12) Do you know approximately, what percentage of your items do not belong to families and, therefore, can be replenished individually?
(Please key in a value): ?

(13) Do you feel that economies resulting from taking advantage of these interactions are significant enough to warrant a special system?
(Please key in yes or no): ?

Mr. Smith could not answer questions 12 and 13. PROCTOR explains that it unable to assess the necessity of joint ordering support. This explanation is generated from data that PROCTOR has determined and from the representation of its internal procedures.

A decision concerning the necessity of a component to handle joint ordering constraints could not be made. The reasons for the decision are that

1 your judgement concerning the significance of joint ordering constraints of the purchasing department is not known.
2 the percentage of non-family items of the purchasing department is not known.

PROCTOR mentions that family aggregation is possible even though it cannot evaluate whether is is needed.

A component to handle family aggregation in the purchasing department is possible. The reason for the decision is that you decided that the family aggregation of the purchasing department is possible.

PROCTOR tries to continue in the investigation. Notice that the number of items and the number of families does not depend on the evaluation of the necessity of a joint-ordering procedure.

(14) Mr. Smith, how many different items does your purchasing department control?

Please select one of the following:

1 less than 11
2 between 11 and 100
3 between 101 and 500
4 between 501 and 1000
5 between 1001 and 5000
6 between 5001 and 10000
7 between 10001 and 25000
8 between 25001 and 50000
9 more than 50000

(Enter here): 6

(15) How many families (groups of items) are there?

Please select one of the following:

1 less than 11
2 between 11 and 50
3 between 51 and 100
4 between 101 and 250
5 between 251 and 500
6 more than 500

(Enter here): 2

PROCTOR cannot proceed any further. The percentage of non-family items is needed to determine the number of family items which is used to evaluate the feasibility of providing joint ordering support. (PROCTOR will only suggest joint ordering support when a significant number of items are involved in family aggregation.)

A decision concerning the feasibility of a component to handle joint ordering constraints in the purchasing department could not be made. This is because the average number of the family items of the purchasing department is not known and a decision concerning the necessity of a module for joint ordering constraints could not be made.

PROCTOR tries an alternate strategy: perhaps Mr. Smith would be satisfied with a reporting

procedure instead. Mr. Smith decides to interrupt the investigation.
(16) It is sometimes desirable to aggregate similar items into families merely for reporting purposes. Would you like family aggregation to be considered for this reason?
(Please key in yes or no): !

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 5

The following is a list of possible summaries.

Please select one or more of the following:

1 print a summary of the facts collected
2 print a summary of the recommendations so far
3 print responses to questions

(Enter here): 2
PROCTOR can supply a summary evaluation at any time during the investigation. The reader should note that this text is not prestored but is generated from the OWL concept structure.
Date of session: April 27, 1976
Time session started: 7:25 pm

User's name: Mr. Adam Smith

The following data is about the purchasing department.

A decision concerning the necessity of a component to handle joint ordering constraints in the purchasing department could not be made. The reasons for the decision are that

1 your judgement concerning the significance of joint ordering constraints of the purchasing department is not known.
2 the percentage of non-family items of the purchasing department is not known.

A decision concerning the feasibility of a component to handle joint ordering constraints could not be made. The reason for the decision is that the average number of the family items of the purchasing department is not known and a decision concerning the necessity of a component to handle joint ordering constraints in the purchasing department could not be made.

A module for family aggregation is possible. This is because you decided that the family aggregation of the purchasing department is possible.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help

4 change answers
5 summarize the analysis

(Enter here): 4

This section illustrates the general mechanism for changing answers. Mr. Smith specifies the answer he wants changed by giving PROCTOR a question number. Here he requests that PROCTOR reask question 13 concerning the significance of joint ordering interactions.

The current question numbers range from 1 to 16. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 13

So far the following will be changed: The response to question 13 about your judgement concerning the significance of joint ordering constraints of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

PROCTOR continues by asking Mr. Smith for his new answer.
(13) Mr. Smith, do you feel that economies resulting from taking advantage of these interactions are significant enough to warrant a special system?
(Please key in yes or no): yes

PROCTOR changes the answer without recomputing the entire session. Only evaluations concerning necessity and feasibility are redetermined. Notice that the evaluation of the possibility of family aggregation is not redetermined. PROCTOR assumes that a module is needed without knowing the percentage of items that are involved in joint ordering interactions. It still cannot evaluate the feasibility.

A module for joint ordering constraints is needed. This is because you decided that the joint ordering constraints of the purchasing department are significant. A decision concerning the feasibility of a module for joint ordering constraints could not be made. The reason for the decision is that the average number of the family items of the purchasing department is not known.
(16) It is sometimes desirable to aggregate similar items into families merely for reporting purposes. Would you like family aggregation to be considered for this reason?
(Please key in yes or no): !

Mr. Smith interrupts PROCTOR. He requests that question 12 concerning the percentage of non-family items be reasked.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

The current question numbers range from 1 to 16. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 12

So far the following will be changed: The response to question 12 about the percentage of non-family items of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(12) Do you know approximately, what percentage of your items do not belong to families and, therefore, can be replenished individually?
(Please key in a value): 30

PROCTOR has sufficient information to evaluate the feasibility and the type of component to handle joint ordering interactions. Notice that PROCTOR [illegible] only the facts that are affected by the change to question 12. (It does not [illegible] the evaluation concerning the necessity of a module.)
Notice also that the text for the details of the module is "canned" text. Everything else is generated.

A component to handle joint ordering constraints is feasible. This is because a module for family aggregation is possible and a module for joint ordering constraints is needed, and the average number of the family items of the purchasing department is more than 20. Concerning the details of a module for joint ordering constraints in the purchasing department: Items that experience joint ordering interactions and that share common inventory characteristics should be aggregated into families. The reasons for the decision are that

1 a component to handle joint ordering constraints in the purchasing department is feasible.
2 joint ordering constraints are present.

(16) Now it is sometimes desirable to aggregate similar items into families merely for reporting purposes. Would you like family aggregation to be considered for this reason?
(Please key in yes or no): !

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 5

Now the following is a list of possible summaries.

Please select one or more of the following:

1 print a summary of the facts collected

2 print a summary of the recommendations so far
3 print responses to questions

(Enter here): 2

Mr. Smith requests that PROCTOR print a summary report of recommendations. PROCTOR prints all evaluations it has made.

Date of session: April 27, 1976
Time session started: 7:25 pm

User's name: Mr. Adam Smith

The following data is about the purchasing department.

A module for joint ordering constraints is needed. This is because you decided that the joint ordering constraints of the purchasing department are significant. A module for joint ordering constraints is feasible. The reasons for the decision are that
1 a component to handle family aggregation is possible.
2 a component to handle joint ordering constraints in the purchasing department is needed.
3 the average number of the family items of the purchasing department is more than 20.

Concerning the details of a module for joint ordering constraints: Items that experience joint-ordering interactions and that share common inventory characteristics should be aggregated into families. This is because a component to handle joint ordering constraints in the purchasing department is feasible and joint ordering constraints are present in the purchasing department. A component to handle family aggregation is possible. The reason for the decision is that you decided that the family aggregation of the purchasing department is possible.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 5

Mr. Smith, the following is a list of possible summaries.

Please select one or more of the following:

1 print a summary of the facts collected
2 print a summary of the recommendations so far
3 print responses to questions

(Enter here): 3
Mr. Smith lists his responses for questions 12 and 13 to insure that the changes have been made.
The current question numbers range from 1 to 16. Now the following is a list of possible summaries of responses to questions.

Please select one of the following:

1 print a summary of all questions
2 print selected questions
3 return to toplevel

(Enter here): 2

You can repeat the following options as many times as you desire.

Please select one of the following:

1 select questions in a range
2 select individual questions
3 print those questions selected so far
4 leave the selection loop

(Enter here): 2

(Please key in the questions you wish listed): 12 13

Do you wish to select more?
(Please key in yes or no): n

You can repeat the following options as many times as you desire.

Please select one of the following:

1 select questions in a range
2 select individual questions
3 print those questions selected so far
4 leave the selection loop

(Enter here): 3

Question 12
concerns the percentage of non-family items of the purchasing department
response: 30

Question 13
concerns your judgement concerning the significance of joint ordering constraints of the purchasing department
response: significant

Mr. Smith, you can repeat the following options as many times as you desire.

Please select one of the following:

1 select questions in a range
2 select individual questions
3 print those questions selected so far
4 leave the selection loop

(Enter here): !

Now you are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 1

Mr. Smith decides to save the session and to continue after a coffee break.
Mr. Smith, do you really want to quit?
(Please key in yes or no): yes

Do you wish to save what you have done so far?
(Please key in yes or no): yes

A record of this session will be saved. Mr. Smith, do want a listing of the session submitted for printing?
(Please key in yes or no): n

****

The return of Mr. Smith. . . .

Welcome back Mr. Smith!

Today is April 27, 1976. The time is 7:38 pm.

You are continuing the analysis started on April 27, 1976 at 7:25 pm.
You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 2

PROCTOR asks if Mr. Smith wishes family aggregation for reporting purposes and not just for joint replenishment purposes.
(16) It is sometimes desirable to aggregate similar items into families merely for reporting purposes. Would you like family aggregation to be considered for this reason?
(Please key in yes or no): n

PROCTOR can now provide evaluations concerning modules for family aggregation and family disaggregation. All text (except comments concerning the details of the type of module) is generated by PROCTOR from its internal representation.

Concerning the details of a module for family aggregation: Items that experience joint-ordering interactions and that are aggregated into families because they share common inventory characteristics should be ordered together to achieve benefits of economies of scale. The reasons for the decision are that

1 joint ordering constraints are present.
2 a module for joint ordering constraints in the purchasing department is feasible.

A component to handle family aggregation is needed. This is because a module for joint ordering constraints in the purchasing department is feasible. A component to handle family disaggregation is needed. This is because a module for family aggregation in the purchasing department is needed and a module for joint ordering constraints is feasible. Concerning the details of a module for family disaggregation in the purchasing department: Procurement amounts that are allocated to families should be allocated to family members so that items in families run out simultaneously. The reasons for the decision are that

1 a module for family disaggregation is needed.
2 a component to handle joint ordering constraints in the purchasing department is feasible.

PROCTOR starts investigations into external constraints.

And Mr. Smith, we will now attempt to identify whether there are external constraints among your items that warrant the development of an aggregate plan and the aggregation of items and families of items into product types. Do you need further information with regards to external interactions?
(Please key in yes or no): yes

The presence of external constraints such as storage limitations, financial constraints, limited capacity of individual vendors, and need to smooth purchasing orders under fluctuating requirements may force the development of a purchasing plan during a long time horizon (usually a year). Items and families of items are then aggregated into product types to facilitate the design and implementation of the plan. An aggregate purchasing plan is required whenever purchasing decisions have to be made looking more than one purchasing lead time ahead, and items are competing for scarce resources under fluctuating demand conditions.

***PROCTOR** uses question 17 through 21 to determine the existence of external constraints in KBS Foods. An aggregate planning module is considered if at least one constraint is present.*

(17) Are there storage constraints that limit the amount of physical inventory you could handle?
(Please key in yes or no): n

(18) And Mr. Smith, are there financial constraints that force you to define a fairly constant purchasing rate each month?
(Please key in yes or no): n

(19) Are there contracts you sign with individual vendors which force you to define a fairly constant purchasing rate every month?
(Please key in yes or no): ?

(20) Are there supply limits on some of your vendors which force you to anticipate some of your purchasing requirements?
(Please key in yes or no): yes

(21) Do you carry seasonal inventories to absorb demand fluctuations?

(Please key in yes or no): yes

PROCTOR evaluates the necessity of a component from the user's judgement of the importance of items and an estimate of the percentage of items affected by external constraints.

(22) Are items involved in external interactions important enough to require a special system? (these items might be very expensive or they could be big sellers)
(Please key in yes or no): yes

(23) Do you know what percentage of your items are affected by these external interactions?
(Please key in a value): 65

A procurement aggregate planning module is needed. This is because you decided that the external constraints of the purchasing department are important.

PROCTOR investigates product aggregation before evaluating aggregate plan feasibility since items and families must usually be further aggregated before a linear programming formulation can be feasible.

(24) Can the items (and/or families) affected by external interactions be grouped into product types (according to similar unit costs, demand patterns, and/or purchasing lead times)?
(Please key in yes or no): y

(25) Now how many product types are there?

Please select one of the following:

1 less than 11
2 between 11 and 20
3 between 21 and 50
4 between 51 and 100
5 more than 100

(Enter here): 4

Notice how PROCTOR makes consistency checks before accepting an answer: it has detected an inconsistency between the number of families and the number of products possible through aggregation. Mr. Smith feels that the number of product types is correct and decides to change his response concerning the number of families.

Mr. Smith, I think I have detected an error.

The number of product types exceeds the number of families.

You may change one or more of the following.

1 "between 51 and 100", the response to question 25 concerning the number of the product types of the purchasing department
2 "between 11 and 50", the response to question 15 concerning the number of the families of the purchasing department

(Please select one or more): 2

So far the following will be changed: The response to question 15 concerning the number of the families of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

(15) Now Mr. Smith, how many families (groups of items) are there?

Please select one of the following:

1 less than 11
2 between 11 and 50
3 between 51 and 100
4 between 101 and 250
5 between 251 and 500
6 more than 500

(Enter here): 4

PROCTOR accepts the change. Previous evaluations are unaffected and PROCTOR proceeds to consider the aggregate plan in detail.

(26) Mr. Smith, do you currently have an aggregate purchasing plan?
(Please key in yes or no): !

Mr. Smith interrupts the session to print information concerning questions 15 and 25. (We omit details to save space.) Notice that changes have been correctly done.

Question 15
concerns the number of the families of the purchasing department
response: between 101 and 250

Question 25
concerns the number of the product types of the purchasing department
response: between 51 and 100

PROCTOR continues the session. It must determine an appropriate time horizon and time period division for the aggregate plan in order to estimate the number of variables required.

An existing aggregate plan can sometimes provide insight into appropriate answers.
(26) Now Mr. Smith, do you currently have an aggregate purchasing plan?
(Please key in yes or no): n

(27) Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 1

Mr. Smith selects a horizon of 6 months for the aggregate plan. PROCTOR knows that a horizon of at least a year is required for aggregate plan which [illegible] (see question 21) are involved and indicates the error.

Mr. Smith, I think I have detected an error.

A time horizon of less than 6 months is inappropriate for a situation with seasonal inventories.

You may change one or more of the following.

1 "less than 6 months", the answer to question 27 about the length of the horizon of the aggregate purchasing plan of the purchasing department
2 "present", the answer to question 21 about seasonal-inventories in the purchasing department

(Please select one or more): 1

Please try again....
(27) Now Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 4

Mr. Smith cannot decide on an appropriate horizon. PROCTOR suggests a horizon of at least a year and Mr. Smith agrees.

(28) It is common to do aggregate planning with a year horizon. Is it ok to assume that the time horizon be more than 12 months long?
(Please key in yes or no): yes

Mr. Smith cannot decide on an appropriate time period division. PROCTOR again recommends one month which is the most common aggregate planning period.
(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days

10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 12

(30) It is common to do aggregate planning monthly. Is it ok to assume that the time horizon be divided into 1 month periods?
(Please key in yes or no): y

PROCTOR decides that an LP formulation is infeasible since the estimated number of variables exceeds 1500, the assumed maximum for the number of variables allowed in most commercial LP code. (Notice that an explanation capability would be useful here: Mr. Smith might want to know how the number of variables was computed.)

A procurement aggregate planning module is infeasible. The reasons for the decision are that
1 the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500.
2 a procurement aggregate planning module is needed.

The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered.
(31) It is sometimes useful to aggregate items up to the product level for reporting purposes. Would you like product aggregation to be considered for this reason?
(Please key in yes or no): 1

Mr. Smith requests that question 29 be reasked. An longer time period will decrease the number of variables required for the aggregate plan. (Details are omitted to save space.)

So far the following will be changed: The response to question 29 concerning the time period division of the aggregate purchasing plan of the purchasing department.

PROCTOR reasks the question. It delays the redetermination of the feasibility of the LP until it determines the possibility of a middle range forecasting system.

(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days
10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 6

PROCTOR stops to evaluate the possibility of a middle-range forecasting system

Now Mr. Smith, do you need an explanation of the difference between the demand for an end item and the shipments (or sales) of the end item?
(We will denote by end items all those items that are requested directly by a customer.)
(Please key in yes or no): yes

One should distinguish between the demand of an item, which is derived directly from the final customer requirements, and the shipments or sales of that item. Demand is the input to the procurement process; sales and shipments are the output. Due to delays, shortages, backorders, cancellations, etc., there is normally a significant difference in the magnitude and timing of demand and sales.

Constant demand patterns can be forecast very simply. Trends and seasonalities warrant complicated procedures and good demand histories.
(32) Do the end items exhibit increasing or decreasing trends in their demand pattern?
(Please key in yes or no): no

(33) Are the end items affected by seasonalities?
(Please key in yes or no): yes

Some companies keep records of their customer demand.
(34) Mr. Smith, do you maintain demand records for most of your items?
(Please key in yes or no): n

In determining data requirements, PROCTOR must evaluate the need for a middle range forecasting system. It interrupts the evaluations to consider long lead time items: a middle range forecasting system is required to control items with long lead times. The unavailability of data will be more serious if a middle range forecasting system is required both for the aggregate plan and to control long lead time items.

Now do you need a definition of purchasing lead time?
(Please key in yes or no): yes

The purchasing lead time is the time that elapses from the moment a replenishment order is triggered until the first major portion of the order is placed on the shelf. Part of the purchasing lead time is caused by internal administrative procedures, and part is due to in-transit time and order processing delays at the supplier. The following are typical components of a purchasing lead time:

```
                    purchasing lead time issue of
receipt at purchase                                        warehouse
requisition

  review     vendor quoted   receiving   inspection   handling
   time       lead time         time         time         time
```

The review time is the time that elapses between the release of the purchase requisition and the receipt of the order by the supplier. It includes an average administrative waiting time, the buyer's intervention to translate the purchase requisition into a purchase order, and the time required to transmit the order to the appropriate vendor. The receiving time includes an average waiting time in receiving, and an allowance for counting and checking

the order. the inspection time (if needed), includes an average waiting time and the actual inspection time.

(35) Are there items with extremely long purchasing lead times?
(Please key in yes or no): ?

Imported items are items that have long lead times.
(36) Do you import any of your purchased items?
(Please key in yes or no): n

PROCTOR cannot decide if long lead time support is required since the absence of long lead time items has not been confirmed.

A decision concerning the necessity of a module for long lead time determination in the purchasing department could not be made. The reason for the decision is that it is not known whether long lead time items in the purchasing department are present.

A middle range system is necessary for the aggregate plan.
A component to handle middle-range forecasting in the purchasing department is needed. This is because a procurement aggregate planning module is needed.

PROCTOR decides to continue the investigation of data availability since it has now determined that a middle range forecasting system is necessary.

Sales and back order records can be used to estimate past demands. (Note, PROCTOR is relatively undeveloped in its considerations of data requirements. It should investigate the possibility and cost of recreating demand records as part of these investigations.)

(37) Mr. Smith, do you maintain shipment or sales records for most of your end items?
(Please key in yes or no): yes

(38) Mr. Smith, do you keep records of backorders?
(Please key in yes or no): ?

(39) Now Mr. Smith, do your sales records have missing data?
(Please key in yes or no): n

(40) Now what is the average length of your sales records?

Please select one of the following:

1 less than one year
2 one year
3 two years
4 3 years
5 more than 3 years

(Enter here): 5

(41) How do your sales records show past requirements?

Please select one of the following:

1 by day
2 by week
3 by month
4 by quarter
5 by year
6 by transaction

(Enter here): 3

PROCTOR cannot make a definite decision without knowing the availability of back order records.

A decision concerning availability the data for forecasting of the purchasing department could not be made. This is because it is not known whether backorder records are present.
(39) It is sometimes useful to aggregate items up to the product level for reporting purposes. Would you like product aggregation to be considered for this reason?
(Please key in yes or no): !

Mr. Smith interrupts to give a definite answer to question 38.

So far the following will be changed: The response to question 38 concerning backorder records.

PROCTOR reasks the question.

(38) Do you keep records of backorders?
(Please key in yes or no): yes

PROCTOR is now able to provide a decision. It decides that data is available and that a forecasting system should be possible.

The data for forecasting of the purchasing department is available. The reasons for the decision are that

1 sales records are present.
2 backorder records in the purchasing department are present.
3 errors are absent in the sales records of the purchasing department.
4 a component to handle middle-range forecasting in the purchasing department is needed.
5 the length of the sales records of the purchasing department is not less than one year.

Since you have records of sales and backorders that are error free, it should be possible to recreate a good estimate of your demand patterns.

Notice, PROCTOR knows that at least a year of data will be required to handle seasonal forecasting

A component to handle middle-range forecasting is possible. The reasons for the decision are that

1 the data for forecasting of the purchasing department is available.
2 the average length of the data for forecasting of the purchasing department is not less than one year.

PROCTOR returns to its considerations of an aggregate plan. (It will continue forecasting

investigations in a later part of the session.) An aggregate planning module is feasible and PROCTOR comments on the type of model that must be used. (This knowledge could be elaborated to provide a more detailed description of an LP.)

A procurement aggregate planning module is feasible. The reasons for the decision are that
1 the average number of the variables of the aggregate purchasing plan of the purchasing department is not more than 1500.
2 the average number of the constraints of the aggregate purchasing plan of the purchasing department is not more than 1000.
3 a component to handle middle-range forecasting is possible.
4 a procurement aggregate planning module is needed.

Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. The reasons for the decision are that
1 a procurement aggregate planning module is feasible.
2 external constraints are present.

Product aggregation is needed to make the aggregate plan feasible. In addition, a product disaggregation routine is required to allocate planned procurement amounts to family members.

A component to handle product aggregation in the purchasing department is needed. The reason for the decision is that a procurement aggregate planning module is feasible. Concerning the details of a component to handle product aggregation: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. This is because external constraints are present in the purchasing department and a procurement aggregate planning module is feasible. A module for product disaggregation in the purchasing department is needed. This is because a module for product aggregation is needed and a procurement aggregate planning module is feasible.

PROCTOR requires an estimate of family ordering costs before it decides on the type of routine to be used. If costs are small, an equalization of run out times routine will be appropriate. Otherwise, Knapsack or Hax-Meal should be used.
(42) Mr. Smith, please give a rough estimate of the average direct ordering cost.

Please select one of the following:

1 less than 0.5 dollars
2 between 0.5 and two dollars
3 between two and 5 dollars
4 between 5 and 10 dollars
5 between 10 and 25 dollars
6 between 25 and 50 dollars
7 between 50 and 100 dollars
8 more than 100 dollars

(Enter here): 3

PROCTOR remembers that multi-item orders exist. To estimate family ordering costs, it uses the maximum of the estimated cost for ordering all members of a typical family and the cost for placing a typical multi-item order.

(43) On the average, how many items are there in an order?

Please select one of the following:

1 less than 5
2 between 5 and 10
3 between 11 and 25
4 between 26 and 50
5 more than 50

(Enter here): 3

Knapsack is the most appropriate disaggregation routine.

Concerning the details of a module for product disaggregation in the purchasing department: You should use the Knapsack or Hax-meal disaggregation scheme in allocating planned product type procurement amounts to family and non-family item members of product types. These schemes work best for situations with setup and holding costs such as yours. The reasons for the decision are that

1 a component to handle product disaggregation is needed.
2 the estimated family and non-family item ordering cost of the purchasing department is more than two dollars.
3 a procurement aggregate planning module is feasible.

PROCTOR starts investigations into inventory characteristics

This section considers a lead time determination module. A module will be considered when variable lead time items are present, especially if a significant number of items have variable lead times or if the user feels that these items are important enough to require close control.

(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant
3 fairly variable
4 extremely variable

(Enter here): 3

(45) Now are the items that exhibit variable lead-times important enough to require close control?
(Please key in yes or no): yes

(46) Mr. Smith, can you give a percent estimate of the number of your items that are affected by lead time dependencies?
(Please key in a value): 15

A module for lead time determination is needed. The reason for the decision is that you decided that the items with variable lead times of the purchasing department are important.

With lead time dependencies, lead time forecasting may be possible.
(47) And Mr. Smith, does the lead time variability depend on the order size?
(Please key in yes or no): n

(48) Does the lead time variability depend on the season?
(Please key in yes or no): yes

Vendor dependencies exist only when there are multi-vendor items.
(49) Do you have items that can be purchased from several different vendors?
(Please key in yes or no): n

(50) Mr. Smith, do you keep historical records of lead times?
(Please key in yes or no): yes

A forecasting system is possible since seasonal dependencies exist and since lead time records are available.

A lead time forecasting module is possible. The reason for the decision is that lead time dependencies are present. Concerning the details of a component to handle lead time determination: A lead time forecasting system should be implemented for items that have seasonal lead time dependencies. The reasons for the decision are that

1 a lead time forecasting module is possible.
2 seasonal lead time dependencies are present.

PROCTOR notes that it cannot further evaluate support for long lead times since it does not know if long lead time items are possible. (It determined this fact when it investigated the necessity of a middle range forecasting system.)

A decision concerning the type of a module for long lead time determination could not be made. The reason for the decision is that it is not known whether long lead time items are present.

PROCTOR begins investigations into vendor selection support

No vendor selection component is required since multiple vendor items are absent: vendor investigations are not continued.
A component to handle vendor selection in the purchasing department is unnecessary. The reason for the decision is that vendor tradeoffs are absent in the purchasing department.

PROCTOR begins an investigation into a module to determine order quantities for non-aggregately planned items and families.

And Mr. Smith, do you need an explanation with regards to the components of holding cost associated with carrying a unit of an item in inventory during a year?
(Please key in yes or no): yes

The primary components of the inventory holding cost are: cost of capital tied up in inventory, handling, pilferage, damage, breakage, rust, deterioration, evaporation, obsolesence, storage, insurance, taxes, etc. normally, the most important components of the

inventory holding costs are the cost of capital and taxes. The relevant part of these costs is that one that is directly variable with inventory value. since the incidence of these components in establishing the inventory holding costs depends on the unit cost of the item, the impact of these components is combined into a single figure representing the percentage of the unit cost of the item which accounts for the inventory cost. Thus, for example, if an item with a unit cost of $10.00 has a 20% holding cost it means that it cost $2.00 to keep a unit of that item in inventory for a year.

(51) And Mr. Smith, what is the purchase cost for most of your items?

Please select one of the following:

1 less than 0.5 dollars
2 between 0.5 and two dollars
3 between two and 5 dollars
4 between 5 and 10 dollars
5 between 10 and 25 dollars
6 between 25 and 50 dollars
7 between 50 and 100 dollars
8 more than 100 dollars

(Enter here): 1

Mr. Smith has just realized that he gave a wrong answer to question 49. He has many items that are supplied by more than one vendor. He interrupts PROCTOR to request that question 49 be reasked.

So far the following will be changed: The answer to question 49 concerning multi-vendor items in the purchasing department.

PROCTOR reasks the question and recomputes its evaluations for lead time support and vendor support.

(49) Do you have items that can be purchased from several different vendors?
(Please key in yes or no): yes

Note that an answer of no to question 52 leaves the previous evaluations concerning lead time support unaffected. PROCTOR simply skips the recalculations and proceeds to investigate a vendor selection component.

(52) Do different vendors have significantly different purchasing lead times?
(Please key in yes or no): n

There are no vendor tradeoffs so a module for vendor selection is unnecessary.
(53) Mr. Smith, does the price of the item change with each individual vendor?
(Please key in yes or no): n

A module for vendor selection is unnecessary. The reason for the decision is that vendor tradeoffs in the purchasing department are absent.

PROCTOR continues at the point where it was interrupted.
(51) And Mr. Smith, what is the purchase cost for most of your items?

Please select one of the following:

1 less than 0.5 dollars
2 between 0.5 and two dollars
3 between two and 5 dollars
4 between 5 and 10 dollars
5 between 10 and 25 dollars
6 between 25 and 50 dollars
7 between 50 and 100 dollars
8 more than 100 dollars

(Enter here): 3

(54) Mr. Smith, provide a rough estimate of the inventory holding cost expressed as a percentage of the item's unit cost.

Please select one of the following:

1 less than 10 percent
2 between 10 and 15 percent
3 between 15 and 20 percent
4 between 20 and 25 percent
5 between 25 and 30 percent
6 more than 30 percent

(Enter here): 4

From previous calculations concerning ordering costs (see type to family disaggregation routine) and from questions 53 and 54, PROCTOR is able to evaluate the suitability of an economic order quantity routine. (The 0.05 computation is a very rough approximation for an evaluation concerning the unsuitability of EOQs for situations with very large holding costs.)

A routine for computing eoq's is possible. This is because a module for middle-range forecasting is possible and the estimated family and non-family item ordering cost of the purchasing department is not less than two dollars and the estimated family and non-family item ordering cost of the purchasing department divided by the estimated item holding-cost of the purchasing department is not less than 0.05.

Replenishment rates determine the type of EOQ formula to be used.
(55) Do you have any items whose purchase orders are not received all at once?
(Please key in yes or no): y

PROCTOR remembers that economies of scale are present and recommends that a suitable formula be used for items with economies of scale.

Concerning the details of a routine for computing eoq's: Order quantities may be determined by the standard eoq formula for most of your items. Those items that experience non-instantaneous replenishment rates should use the eoq formula that takes replenishment rates into consideration. A formula that takes economies of scale into consideration should be used in determining the order quantities of items and families that have certain economies of scale in ordering from vendors. This is because a routine for computing eoq's is possible and a module for joint ordering constraints is feasible and joint ordering constraints are present and items with non-instantaneous replenishment rates in the purchasing department are present.

Special support is required for extremely expensive items. Unfortunately, PROCTOR cannot make an evaluation based on Mr. Smith's answers.
(56) Are there extremely expensive items that deserve a special control system?
(Please key in yes or no): ?

A decision concerning the necessity of a routine for determining order quantities of extremely expensive items could not be made. This is because it is not known whether extremely-expensive items in the purchasing department are present.

PROCTOR completes investigations into forecasting

(57) Do you keep records of seasonal indices (or seasonal factors) for the seasonal end items?
(Please key in yes or no): !

Mr. Smith has other ideas: he decides to change his answer concerning non-instantaneous replenishment rates.

So far the following will be changed: The response to question 55 about items with non-instantaneous replenishment rates. n.center *Execution continues.*
(55) Do you have any items whose purchase orders are not received all at once?
(Please key in yes or no): n

PROCTOR recomputes the evaluation of the details of the EOQ routine but does not recompute the evaluations into the suitability of an EOQ routine.

Concerning the details of a routine for computing eoq's: The standard economic order quantity formula should be used for most of your items. A formula that takes economies of scale into consideration should be used in determining the order quantities of items and families that have certain economies of scale in ordering from vendors. The reasons for the decision are that

1 a routine for computing eoq's is possible.
2 a module for joint ordering constraints is feasible.

Forecasting considerations continue ...
Records of seasonal indices are the best source of data for forecasting seasonal items.
(57) Now do you keep records of seasonal indices (or seasonal factors) for the seasonal end items?
(Please key in yes or no): n

A system is still possible since PROCTOR has previously determined that data for forecasting is available.

A component to handle the forecasting of seasonal items is possible. The reasons for the decision are that

1 the data for forecasting of the purchasing department is available.
2 the average length of the data for forecasting of the purchasing department is not less than one year.

Special support can be provided when only a few patterns exist.
(58) How many different seasonal patterns do you have among your end items?

Please select one of the following:

1 1
2 2
3 3
4 4
5 5
6 more than 5

(Enter here): 6

Limited sales season items are seasonal items which have periods of no sales. KBS has several such items (Christmas candy, for example). Support can easily be provided with the normal seasonal forecasting system

(59) Do you have seasonal items whose demand suddenly terminates at the end of the season?
(Please key in yes or no): yes

(60) Are these limited sales season items important enough to require a special control system?
(Please key in yes or no): yes

Overage costs are important in deciding if support is necessary.
(61) And Mr. Smith, what do you do if the stock of the end-season item exceeds the demand at the end of the season?

Please select one or more of the following:

1 liquidate at salvage value
2 hold until next season
3 write off as obsolete

(Enter here): 1 2

(62) Approximately what percentage of your end items are end-season items?
(Please key in a value): 10

A module for the forecasting of limited-sales-season items is needed. This is because you decided that the limited-sales-season items of the purchasing department are important.

PROCTOR now considers details of support for items with unusual demand patterns. These items will be controlled as special cases of the normal middle range forecasting system.

(63) Are there slow moving items (i.e. items with demand of less than five units per month)?
(Please key in yes or no): yes

(64) Are these slow movers important enough to require a special control system?
(Please key in yes or no): yes

(65) Can you give a the percentage of items that are slow movers?
(Please key in a value): ?

A module for the forecasting of slow-moving items is needed. The reason for the decision is that you decided that the slow-moving items of the purchasing department are important. A component to handle the forecasting of slow-moving items is possible. The reason for the decision is that the data for forecasting of the purchasing department is available.

Concerning the details of a module for the forecasting of slow-moving items: The forecasting of demand for slow movers can be done by exponential smoothing with a very small smoothing factor. This is because a module for the forecasting of slow-moving items in the purchasing department is needed and a component to handle the forecasting of slow-moving items in the purchasing department is possible. A module for the forecasting of seasonal items is needed. The reason for the decision is that seasonal items are present.
(66) Are there items with lumpy demand (i.e erratic demand behavior where periods of very slow demand are followed by sudden high demand requirements)?
(Please key in yes or no): n

A module for the forecasting of items with erratic demand is unnecessary. The reason for the decision is that items with erratic demand in the purchasing department are absent. A component to handle the forecasting of items with trends is unnecessary. This is because items with trends are absent.
(67) Do you have fashionable items (i.e. items that have a short selling life, high obsolescence, and limited reorder opportunities)?
(Please key in yes or no): n

A component to handle the forecasting of fashionable items is unnecessary. This is because fashionable items are absent.
(68) Do you carry promotions that greatly affect the demand pattern of your end items?
(Please key in yes or no): ?

A decision concerning the necessity of a component to handle the forecasting of promoted items could not be made. This is because it is not known whether promoted items are present.
(69) Mr. Smith, do you carry advertising campaigns that greatly affect the demand pattern of your end items?
(Please key in yes or no): ?

A decision concerning the necessity of a component to handle the forecasting of advertised items in the purchasing department could not be made. This is because it is not known whether advertised items are present.
(70) Do you think it is important to provide support for predicting the growth, maturity and decay of your items?
(Please key in yes or no): n

A module to support the prediction of item life patterns is unnecessary. The reason for the decision is that you decided that the support of prediction item-life is unimportant.
(71) Do you have abnormally large orders (due to special orders, errors, promotions, etc.) that you handle as special orders you would like to be screened out of the normal inventory control procedures?
(Please key in yes or no): yes

(72) Now are these abnormally large orders (due to special orders, errors, promotions, etc.) frequent enough to require a routine system to be set up
(Please key in yes or no): n

A module to filter large orders is unnecessary. The reason for the decision is that you decided that the control of items that experience large orders of the purchasing department is unimportant.

PROCTOR can now describe the details of the module for middle range forecasting support.

Concerning the details of a component to handle middle-range forecasting: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. This is because a module for the forecasting of seasonal items in the purchasing department is needed and a component to handle the forecasting of seasonal items is possible and a module for the forecasting of slow-moving items in the purchasing department is needed and a module for the forecasting of slow-moving items is possible and a procurement aggregate planning module is feasible or a module for joint ordering constraints is feasible.

This completes a first session. PROCTOR returns to top level and asks for further instructions: responses can be checked for correctness; evaluations may be summarized. Mr. Smith decides to save the session before continuing any further. A good idea!

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 1

And Mr. Smith, do you really want to quit?
(Please key in yes or no): yes

Do you wish to save what you have done so far?
(Please key in yes or no): yes

A record of this session will be saved. Do want a listing of the session submitted for printing?
(Please key in yes or no): n

****

Welcome back Mr. Smith!

Today is April 27, 1976. The time is 8:03 pm.

You are continuing the analysis started on April 27, 1976 at 7:38 pm. You are at top level.
Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith decides that seasonal lead time dependencies are not the source of KBS's variable lead times: he requests a change to question 44.

The current question numbers range from 1 to 72. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 44

So far the following will be changed: The response to question 44 concerning the degree of variability of the lead-times of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant
3 fairly variable
4 extremely variable

(Enter here): !

An error: Mr. Smith requested the wrong question to be reashed. He interrupts PROCTOR in the middle of a change and requests that question 48 be changed.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

The current question numbers range from 1 to 72. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 48

So far the following will be changed: The response to question 48 concerning seasonal lead time dependencies in the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

PROCTOR must still reask question 44.
(44) How would you characterize the variability of your purchasing lead times for most of your purchased items?

Please select one of the following:

1 very constant
2 reasonably constant
3 fairly variable
4 extremely variable

(Enter here): 3

The response to question 48 is now being changed
(48) Now Mr. Smith, does the lead time variability depend on the season?
(Please key in yes or no): n

There are now no lead time dependencies so a lead time forecasting system is inappropriate. (Notice, this section illustrates PROCTOR's environment mechanism. PROCTOR has invalidated all references to evaluations concerning lead time forecasting.)

PROCTOR considers alternative variable lead time support. Emergency lead times can be used when items are unexpectedly understocked. Safety lead times are useful in providing insurance against stock outs.

(73) Now do your vendors quote an "emergency" lead time for critical items?
(Please key in yes or no): yes

(74) And Mr. Smith, whenever the purchasing lead time is quite uncertain, a safety lead time can be added to the average lead time to take into account the uncertainties associated with lead time calculations. Do you favor the addition of a safety lead time?
(Please key in yes or no): yes

(75) Are there quantity restrictions associated with the emergency lead time?
(Please key in yes or no): yes

(76) Now Mr. Smith, is there a price increase associated with the emergency lead time?
(Please key in yes or no): yes

PROCTOR redetermines the details of a system for lead time support.

Concerning the details of a component to handle lead time determination: A safety lead time should be added to your best current estimate of the procurement lead time when order amounts are to be determined. Emergency lead times should be used only when items are unexpectedly stocked out. This is because emergency lead-times are present and restrictions are present and you decided that the safety lead-times of the purchasing department are appropriate.

PROCTOR has nothing more to do: it awaits further instructions.

You are at top level. Please select one of the following:

1 quit

2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith is not satisfied with the one quarter time period for the aggregate plan and requests that question 29 be reasked.

The current question numbers range from 1 to 76. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 29

So far the following will be changed: The answer to question 29 about the time period division of the aggregate purchasing plan of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(29) What time periods do you think you should use to divide your time horizon?

Please select one of the following:

1 1 calendar week
2 2 calendar weeks
3 3 calendar weeks
4 4 calendar weeks
5 1 calendar month
6 1 calendar quarter
7 1 calendar semester
8 5 working days
9 10 working days
10 20 working days
11 4-4-5 week division
12 I don't know

(Enter here): 5

Unfortunately, Mr. Smith forgot why he chose such an aggregate time period: an LP was infeasible unless time periods or product types could be aggregated. The mistake illustrates how PROCTOR need not recompute the entire session for changes in quantitative information.

A procurement aggregate planning module is infeasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500 and a procurement aggregate planning module is needed. The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered.

In changing the number of time periods, Mr. Smith affected the evaluation of the feasibility of an aggregate plan and in turn, the evaluations for the middle range forecasting system. If

an aggregate plan is infeasible, it may be that no middle range forecasting system is required. PROCTOR, therefore, recomputes evaluations of forecasting that are affected by the change in the evaluation of aggregate plan infeasibility. Here, a middle range system is still required since support is needed for a joint ordering interactions module.

Concerning the details of a module for middle-range forecasting: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. This is because a component to handle the forecasting of seasonal items is needed and a component to handle the forecasting of seasonal items is possible and a module for the forecasting of slow-moving items is needed and a module for the forecasting of slow-moving items is possible and a component to handle joint ordering constraints is feasible.

Evaluations of the necessity of product aggregations are affected. Mr. Smith states that he does not want aggregation for reporting purposes. PROCTOR concludes that product aggregation is unnecessary based on current evaluations: why aggregate if an LP is infeasible?

(31) It is sometimes useful to aggregate items up to the product level for reporting purposes. Would you like product aggregation to be considered for this reason?
(Please key in yes or no): n

A module for product aggregation is unnecessary. This is because a procurement aggregate planning module is infeasible.

PROCTOR returns to the top. . . .

And Mr. Smith, you are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

PROCTOR assumed a time horizon of more than 12 months for the aggregate plan. Mr. Smith decides to specify a horizon of 6 to 12 months hoping that this will change the number of variables in the LP. (Clearly, an explanation system and some sort of debugging facility will someday be required if the user is completely unfamiliar with the methodology. We assume, however, that the user is intelligent enough to know that such a change can affect the number of variables in an LP.)

The current question numbers range from 1 to 76. Please key in the numbers corresponding to questions whose answers you wish to change.
(Please key them in): 27

So far the following will be changed: The answer to question 27 concerning the length of the horizon of the aggregate purchasing plan of the purchasing department.
Do you want to change any more?
(Please key in yes or no): n

Do you wish to delete any requests?
(Please key in yes or no): n

(27) And Mr. Smith, can you give an estimate of an appropriate time horizon for an aggregate plan?

Please select one of the following:

1 less than 6 months
2 between 6 and 12 months
3 more than 12 months
4 not known

(Enter here): 2

The evaluations have not changed. PROCTOR simply reaffirms its previous evaluations.

A procurement aggregate planning module is infeasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is more than 1500 and a procurement aggregate planning module is needed. The number of variables required for the aggregate plan makes it computationally impractical. The possibility of aggregating time periods in the planning horizon or further aggregating product types should be considered. Concerning the details of a module for middle-range forecasting in the purchasing department: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. This is because a component to handle the forecasting of seasonal items in the purchasing department is needed and a module for the forecasting of seasonal items is possible and a component to handle the forecasting of slow-moving items in the purchasing department is needed and a component to handle the forecasting of slow-moving items in the purchasing department is possible and a procurement aggregate planning module is feasible and a component to handle joint ordering constraints is feasible. A component to handle product aggregation in the purchasing department is unnecessary. This is because a procurement aggregate planning module is infeasible.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith remembers that he did not specify whether vendor contracts were present. He hopes to remove the infeasibility evaluation by completely specifying the problem.

So far the following will be changed: The response to question 19 concerning vendor contracts.

PROCTOR continues execution. . . .

Notice that this change has absolutely no effect on the evaluation. The change to the number

of constraints does not affect the evaluations since an aggregate plan is already infeasible due to too many variables.

(19) Are there contracts you sign with individual vendors which force you to define a fairly constant purchasing rate every month?
(Please key in yes or no): n

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 4

Mr. Smith finally takes the most reasonable course of action. With a little thought, he becomes convinced that there is more product aggregation than he had originally specified. He therefore requests a change to question 25.

So far the following will be changed: The answer to question 25 concerning the number of the product types of the purchasing department.

PROCTOR continues execution. . . .

(25) And Mr. Smith, how many product types are there?

Please select one of the following:

1 less than 11
2 between 11 and 20
3 between 21 and 50
4 between 51 and 100
5 more than 100

(Enter here): 3

PROCTOR recomputes only affected evaluations. It does not review the entire session. It finds affected changes by following direct dependencies. Notice that the problem is now feasible but with a different set of conditions: the number of product types has decreased and the number of time periods has increased.

A procurement aggregate planning module is feasible. This is because the average number of the variables of the aggregate purchasing plan of the purchasing department is not more than 1500 and the average number of the constraints of the aggregate purchasing plan of the purchasing department is not more than 1000 and a component to handle middle-range forecasting is possible and a procurement aggregate planning module is needed. Concerning the details of a module for middle-range forecasting in the purchasing department: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. The reasons for the decision are that

1 a component to handle the forecasting of seasonal items is needed and a module for the forecasting of seasonal items is possible.
2 a component to handle the forecasting of slow-moving items is needed and a component to handle the forecasting of slow-moving items is possible.
3 a procurement aggregate planning module is feasible or a component to handle joint ordering constraints is feasible.

A component to handle product aggregation is needed. The reason for the decision is that a procurement aggregate planning module is feasible. A component to handle product disaggregation is needed. This is because a component to handle product aggregation is needed and a procurement aggregate planning module is feasible. Concerning the details of a module for product disaggregation: You should use the Knapsack or Hax-meal disaggregation scheme in allocating planned product type procurement amounts to family and non-family item members of product types. These schemes work best for situations with setup and holding costs such as yours. This is because a module for product disaggregation in the purchasing department is needed and the estimated family and non-family item ordering cost of the purchasing department is more than two dollars and a procurement aggregate planning module is feasible. Concerning the details of a component to handle product aggregation: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. The reasons for the decision are that
1 external constraints are present.
2 a procurement aggregate planning module is feasible.

Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. This is because a procurement aggregate planning module is feasible and external constraints are present.

You are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 5

****

Mr. Smith decides to get complete listings of the problem description, PROCTOR's explanations and his answers. He can use the problem description and explanations as a basis for a report on the usefulness of a hierarchical planning and control system for KBS foods. The listing of his responses is useful in checking missing information and the validity of responses.

The following is a list of possible summaries.

Please select one or more of the following:

1 print a summary of the facts collected
2 print a summary of the recommendations so far
3 print responses to questions

(Enter here): 1 2 3

A summary of facts determined by PROCTOR.

Date of session: April 27, 1976
Time session started: 8:03 pm

User's name: Mr. Adam Smith

The following data is about KBS Foods Ltd.

The address of KBS Foods Ltd is Cambridge MA 02146. The activity of KBS Foods Ltd is purchasing.

The number of the purchasing departments of KBS Foods Ltd is one.

The following data is about the purchasing department.

Concerning the number of the items of the purchasing department, there are many. The number of the items of the purchasing department is between 5001 and 10000. Joint ordering constraints are present. You decided that the joint ordering constraints of the purchasing department are significant. It is not known whether joint quantity discounts are present.

Common ordering costs in the purchasing department are present. Joint economies of transportation are absent. Economies of transportation are absent in the purchasing department. Complex orders in the purchasing department are absent. Multi-item orders are present. A component to handle joint ordering constraints is needed. A component to handle joint ordering constraints is feasible. Concerning the details of a module for joint ordering constraints: Items that experience joint-ordering interactions and that share common inventory characteristics should be aggregated into families. The percentage of family items of the purchasing department is 70. On the average, the number of the family items of the purchasing department is 5250.7. You decided that the family aggregation of the purchasing department is possible. Your desire is to not aggregate families for reporting purposes.

The percentage of non-family items of the purchasing department is 30. On the average, the number of the non-family items of the purchasing department is 2250.3.

The number of the families of the purchasing department is between 101 and 250. A module for family aggregation is possible. A component to handle family aggregation in the purchasing department is needed. Concerning the details of a module for family aggregation: Items that experience joint-ordering interactions and that are aggregated into families because they share common inventory characteristics, should be ordered together to achieve benefits of economies of scale. The number of the product types of the purchasing department is between 21 and 50.

On the average, the number of the product types of the purchasing department is 36. A component to handle family disaggregation in the purchasing department is needed. Concerning the details of a component to handle family disaggregation: Procurement amounts

that are allocated to families should be allocated to family members so that items in families run out simultaneously. External constraints in the purchasing department are present. You decided that the external constraints of the purchasing department are important. The number of the external constraints of the purchasing department is two. Seasonal-inventories are present in the purchasing department. Vendor supply-limits are present in the purchasing department. Vendor contracts are absent in the purchasing department. Financial constraints are absent.

Storage constraints are absent in the purchasing department. Seasonal items in the purchasing department are present. The number of the types of seasonal items of the purchasing department is more than 5.

You wanted assume the length of the horizon of the aggregate purchasing plan of the purchasing department. The length of the horizon of the aggregate purchasing plan of the purchasing department is between 6 and 12 months.

On the average, the number of the variables of the aggregate purchasing plan of the purchasing department is 864. On the average, the number of periods the aggregate purchasing plan of the purchasing department is 12. The average time period division of the aggregate purchasing plan of the purchasing department is one month. The average length of the horizon of the aggregate purchasing plan of the purchasing department is 12 months. A aggregate purchasing plan in the purchasing department is absent. Your desire is to assume the time period division of the aggregate purchasing plan of the purchasing department. The time period division of the aggregate purchasing plan of the purchasing department is one month. On the average, the number of the constraints of the aggregate purchasing plan of the purchasing department is 864.

A procurement aggregate planning module is needed. A procurement aggregate planning module is feasible. Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. The percentage of aggregately-planned items of the purchasing department is 65. You decided that the product aggregation of the purchasing department is possible.

You didn't want to aggregate product-types for reporting purposes. A module for product aggregation is needed. Concerning the details of a module for product aggregation: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. A component to handle middle-range forecasting in the purchasing department is possible. A module for middle-range forecasting is needed. Concerning the details of a module for middle-range forecasting: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. Items with trends are absent in the purchasing department. The data for forecasting of the purchasing department is available. The average length of the data for forecasting of the purchasing department is more than 3 years. Demand records are absent. A decision concerning the necessity of a module for long lead time determination could not be made.

A decision concerning the type of a module for long lead time determination could not be made. It is not known whether long lead time items in the purchasing department are

present.

The degree of variability of the lead-times of the purchasing department is variable. Imported items are absent in the purchasing department. Sales records are present. Data errors are absent.

The length of the sales records of the purchasing department is more than 3 years. Backorder records are present. A module for product disaggregation is needed.

Concerning the details of a component to handle product disaggregation: You should use the Knapsack or Hax-meal disaggregation scheme in allocating planned product type procurement amounts to family and non-family item members of product types. These schemes work best for situations with setup and holding costs such as yours. The estimated family and non-family item ordering cost of the purchasing department is 72.

The average family and non-family item ordering cost of the purchasing department is 12. The computed ordering cost for multi-item orders of the purchasing department is 72. The item ordering cost of the purchasing department is between two and 5 dollars. The average item ordering cost of the purchasing department is 4. The number of the items per order of the purchasing department is between 11 and 25. A component to handle lead time determination in the purchasing department is needed. Concerning the details of a component to handle lead time determination: A safety lead time should be added to your best current estimate of the procurement lead time when order amounts are to be determined. Emergency lead times should be used only when items are unexpectedly stocked out. You decided that the items with variable lead times of the purchasing department are important.

The percentage of items with variable lead times of the purchasing department is 15. Lead time dependencies are absent. Vendor lead time dependencies in the purchasing department are absent. Seasonal lead time dependencies are absent in the purchasing department. Order size lead time dependencies are absent. Multi-vendor items are present. Vendor price tradeoffs are absent. Lead-time records are present. Vendor tradeoffs are absent. A component to handle vendor selection in the purchasing department is unnecessary. A routine for computing eoq's is possible. Concerning the details of a routine for computing eoq's: The standard economic order quantity formula should be used for most of your items. A formula that takes quantity discounts into consideration should be used in determining the order quantities of items and families that have certain economies of scale in ordering from vendors.

The estimated item holding-cost of the purchasing department is 0.92. The purchase cost item of the purchasing department is between two and 5 dollars. The variable item holding cost of the purchasing department is between 20 and 25 percent.

Items with non-instantaneous replenishment rates are absent. It is not known whether extremely-expensive items in the purchasing department are present.

A decision concerning the necessity of a routine for determining order quantities of extremely expensive items could not be made. A module for the forecasting of seasonal items in the purchasing department is possible. A component to handle the forecasting of seasonal items is needed. Records of seasonal factors are absent. A module for the forecasting of limited-sales-season items is needed. Limited-sales-season items are present in the purchasing department. You decided that the limited-sales-season items of the purchasing department are important. The percentage of limited-sales-season items of the purchasing department is 10. The limited-sales season item overage cost of the purchasing department is the cost to liquidate and the off-season holding cost. Slow-moving items are present. You decided that the slow-

moving items of the purchasing department are important. The percentage of slow-moving items of the purchasing department is not known. Concerning the details of a module for the forecasting of slow-moving items: The forecasting of demand for slow movers can be done by exponential smoothing with a very small smoothing factor. A component to handle the forecasting of slow-moving items in the purchasing department is needed. A component to handle the forecasting of slow-moving items is possible. Items with erratic demand are absent in the purchasing department. A module for the forecasting of items with erratic demand is unnecessary. A component to handle the forecasting of items with trends is unnecessary.

Fashionable items are absent. A component to handle the forecasting of fashionable items is unnecessary. It is not known whether promoted items are present.

A decision concerning the necessity of a component to handle the forecasting of promoted items could not be made. It is not known whether advertised items in the purchasing department are present.

A decision concerning the necessity of a module for the forecasting of advertised items in the purchasing department could not be made. A module to support the prediction of item life patterns is unnecessary.

Items that experience large orders are present. You decided that the control of items that experience large orders of the purchasing department is unimportant. A module to filter large orders is unnecessary.

Emergency lead-times are present. Restrictions are present. Emergency lead-time price-increases are present in the purchasing department. Emergency lead-time quantity-restrictions are present. You decided that the safety lead-times are appropriate.

****

A summary of evaluations made by PROCTOR.

Date of session: April 27, 1976
Time session started: 8:03 pm

User's name: Mr. Adam Smith

The following data is about the purchasing department.

A component to handle joint ordering constraints is needed. The reason for the decision is that you decided that the joint ordering constraints of the purchasing department are significant. A component to handle joint ordering constraints is feasible. The reasons for the decision are that

1 a component to handle family aggregation is possible.
2 a module for joint ordering constraints is needed.
3 the average number of the family items of the purchasing department is more than 20.

Concerning the details of a component to handle joint ordering constraints: Items that experience joint-ordering interactions and that share common inventory characteristics should be aggregated into families. The reasons for the decision are that

1 a component to handle joint ordering constraints in the purchasing department is feasible.

2 joint ordering constraints are present.

A module for family aggregation in the purchasing department is possible. The reason for the decision is that you decided that the family aggregation of the purchasing department is possible. A component to handle family aggregation is needed. This is because a module for joint ordering constraints is feasible. Concerning the details of a component to handle family aggregation: Items that experience joint-ordering interactions and that are aggregated into families because they share common inventory characteristics, should be ordered together to achieve benefits of economies of scale. This is because Joint ordering constraints are present and a component to handle joint ordering constraints in the purchasing department is feasible. A module for family disaggregation is needed. This is because a module for family aggregation in the purchasing department is needed and A component to handle joint ordering constraints is feasible. Concerning the details of a module for family disaggregation: Procurement amounts that are allocated to families should be allocated to family members so that items in families run out simultaneously. This is because a module for family disaggregation is needed and a module for joint ordering constraints is feasible. A procurement aggregate planning module is needed. This is because you decided that the external constraints of the purchasing department are important. A procurement aggregate planning module is feasible. The reasons for the decision are that

1 the average number of the variables of the aggregate purchasing plan of the purchasing department is not more than 1500.
2 the average number of the constraints of the aggregate purchasing plan of the purchasing department is not more than 1000.
3 a component to handle middle-range forecasting is possible.
4 a procurement aggregate planning module is needed.

Concerning the details of a procurement aggregate planning module: Procurement amounts for product types, non-product families and non-product non-family items that are subject to external constraints should be determined by means of a linear programming model. This model should optimize holding and storage costs while obeying external constraints. This is because a procurement aggregate planning module is feasible and external constraints are present. A module for product aggregation is needed. The reason for the decision is that a procurement aggregate planning module is feasible. Concerning the details of a module for product aggregation in the purchasing department: Items and families that share common inventory characteristics and demand patterns and that are subject to external constraints should be aggregated into product types for purposes of aggregate planning. The reasons for the decision are that

1 external constraints are present in the purchasing department.
2 a procurement aggregate planning module is feasible.

A module for middle-range forecasting is possible. The reasons for the decision are that

1 the data for forecasting of the purchasing department is available.
2 the average length of the data for forecasting of the purchasing department is not less than one year.

A module for middle-range forecasting in the purchasing department is needed. The reason for the decision is that a procurement aggregate planning module is needed. Concerning the details of a module for middle-range forecasting in the purchasing department: The demand for product types, non-type families and non-family non-type items should be forecast by exponential smoothing. These forecasts may be disaggregated according to the relative annual demands of members. Demand for slow movers can be forecast by exponential smoothing with a small alpha. The reasons for the decision are that

1 a module for the forecasting of seasonal items is needed and a module for the

forecasting of seasonal items is possible.
2 a component to handle the forecasting of slow-moving items is needed and a component to handle the forecasting of slow-moving items is possible.
3 a procurement aggregate planning module is feasible or a module for joint ordering constraints is feasible.

The data for forecasting of the purchasing department is available. Since you have records of sales and backorders that are error free, it should be possible to recreate a good estimate of your demand patterns. This is because sales records are present in the purchasing department and backorder records are present and errors are absent and a module for middle-range forecasting is needed and the length of the sales records of the purchasing department is not less than one year. A decision concerning the necessity of a module for long lead time determination could not be made. The reason for the decision is that it is not known whether long lead time items are present.

A decision concerning the type of a module for long lead time determination in the purchasing department could not be made. This is because it is not known whether long lead time items are present. A module for product disaggregation is needed. This is because a component to handle product aggregation in the purchasing department is needed and a procurement aggregate planning module is feasible. Concerning the details of a component to handle product disaggregation in the purchasing department: You should use the Knapsack or Hax-meal disaggregation scheme in allocating planned product type procurement amounts to family and non-family item members of product types. These schemes work best for situations with setup and holding costs such as yours. The reasons for the decision are that
1 a module for product disaggregation is needed.
2 the estimated family and non-family item ordering cost of the purchasing department is more than two dollars.
3 a procurement aggregate planning module is feasible.

A component to handle lead time determination is needed. This is because you decided that the items with variable lead times of the purchasing department are important. Concerning the details of a module for lead time determination: A safety lead time should be added to your best current estimate of the procurement lead time when order amounts are to be determined. Emergency lead times should be used only when items are unexpectedly stocked out. The reasons for the decision are that
1 emergency lead-times are present in the purchasing department.
2 restrictions are present.
3 You decided that the safety lead-times of the purchasing department are appropriate.

A component to handle vendor selection is unnecessary. This is because vendor tradeoffs are absent.

A routine for computing eoq's is possible. This is because a module for middle-range forecasting is possible and the estimated family and non-family item ordering cost of the purchasing department is not less than two dollars and the estimated family and non-family item ordering cost of the purchasing department divided by the estimated item holding-cost of the purchasing department is not less than 0.05. Concerning the details of a routine for computing eoq's: The standard economic order quantity formula should be used for most of your items. A formula that takes economies of scale into consideration should be used in determining the order quantities of items and families that have certain economies of scale in ordering from vendors. The reasons for the decision are that
1 a routine for computing eoq's is possible.
2 a component to handle joint ordering constraints is feasible.

A decision concerning the necessity of a routine for determining order quantities of extremely expensive items could not be made. This is because it is not known whether extremely-expensive items are present. A module for the forecasting of seasonal items is possible. The reasons for the decision are that

1 the data for forecasting of the purchasing department is available.
2 the average length of the data for forecasting of the purchasing department is not less than one year.

A module for the forecasting of seasonal items in the purchasing department is needed. This is because seasonal items are present in the purchasing department. A module for the forecasting of limited-sales-season items in the purchasing department is needed. The reason for the decision is that you decided that the limited-sales-season items of the purchasing department are important. Concerning the details of a module for the forecasting of slow-moving items: The forecasting of demand for slow movers can be done by exponential smoothing with a very small smoothing factor. This is because a component to handle the forecasting of slow-moving items in the purchasing department is needed and a component to handle the forecasting of slow-moving items is possible. A module for the forecasting of slow-moving items in the purchasing department is needed. This is because you decided that the slow-moving items of the purchasing department are important. A component to handle the forecasting of slow-moving items in the purchasing department is possible. This is because the data for forecasting of the purchasing department is available. A component to handle the forecasting of items with erratic demand is unnecessary. This is because items with erratic demand are absent in the purchasing department. A module for the forecasting of items with trends is unnecessary. This is because items with trends are absent in the purchasing department. A component to handle the forecasting of fashionable items is unnecessary. This is because fashionable items are absent. A decision concerning the necessity of a component to handle the forecasting of promoted items could not be made. This is because it is not known whether promoted items are present.

A decision concerning the necessity of a component to handle the forecasting of advertised items could not be made. This is because it is not known whether advertised items are present. A module to support the prediction of item life patterns is unnecessary. This is because you decided that the support of prediction item-life is unimportant. A module to filter large orders is unnecessary. The reason for the decision is that you decided that the control of items that experience large orders of the purchasing department is unimportant. The current question numbers range from 1 to 76. Now the following is a list of possible summaries of responses to questions.

****

A summary of responses entered by Mr. Smith.

Please select one of the following:

1 print a summary of all questions
2 print selected questions
3 return to toplevel

(Enter here): 1

Question one

concerns the name of KBS Foods Ltd
response: KBS Foods Ltd

Question two
concerns the address of KBS Foods Ltd
response: Cambridge MA 02145

Question 3
concerns whether the activity of KBS Foods Ltd is purchasing
response: yes

Question 4
concerns the number of the purchasing departments of KBS Foods Ltd
response: 1

Question 5
concerns whether there are many items of the purchasing department
response: yes

Question 6
concerns the status of economies of transportation
response: absent

Question 7
concerns the status of common ordering costs
response: not known

Question 8
concerns the status of complex orders
response: absent

Question 9
concerns the status of multi-item orders
response: present

Question 10
concerns the status of joint quantity discounts in the purchasing department
response: not known

Question 11
concerns your judgement concerning the possibility of the family aggregation of the purchasing department
response: possible

Question 12
concerns the percentage of non-family items of the purchasing department
response: 30

Question 13
concerns your judgement concerning the significance of joint ordering constraints of the purchasing department
response: significant

Question 14
concerns the number of the items of the purchasing department
response: between 5001 and 10000

Question 15
concerns the number of the families of the purchasing department
response: between 101 and 250

Question 16
concerns your desire to the family aggregation of the purchasing department
response: not-desired

Question 17
concerns the status of storage constraints
response: absent

Question 18
concerns the status of financial constraints
response: absent

Question 19
concerns the status of vendor contracts in the purchasing department
response: absent

Question 20
concerns the status of vendor supply-limits in the purchasing department
response: present

Question 21
concerns the status of seasonal-inventories in the purchasing department
response: present

Question 22
concerns your judgement concerning the importance of external constraints of the purchasing department
response: important

Question 23
concerns the percentage of aggregately-planned items of the purchasing department
response: 65

Question 24
concerns your judgement concerning the possibility of the product aggregation of the purchasing department
response: possible

Question 25
concerns the number of the product types of the purchasing department
response: between 21 and 50

Question 26
concerns the status of a aggregate purchasing plan

response: absent

Question 27
concerns the length of the horizon of the aggregate purchasing plan of the purchasing department
response: between 6 and 12 months

Question 28
concerns your desire to assume the length of the horizon of the aggregate purchasing plan of the purchasing department
response: desired

Question 29
concerns the time period division of the aggregate purchasing plan of the purchasing department
response: one month

Question 30
concerns your desire to assume the time period division of the aggregate purchasing plan of the purchasing department
response: desired

Question 31
concerns your desire to the product aggregation of the purchasing department
response: not-desired

Question 32
concerns the status of items with trends
response: absent

Question 33
concerns the status of seasonal items
response: present

Question 34
concerns the status of demand records in the purchasing department
response: absent

Question 35
concerns the status of long lead time items in the purchasing department
response: not known

Question 36
concerns the status of imported items
response: absent

Question 37
concerns the status of sales records
response: present

Question 38
concerns the status of backorder records
response: present

Question 39
concerns the status of errors
response: absent

Question 40
concerns the length of the sales records of the purchasing department
response: more than 3 years

Question 41
concerns the periodicity of the sales records of the purchasing department
response: by-month

Question 42
concerns the item ordering cost of the purchasing department
response: between two and 5 dollars

Question 43
concerns the number of the items per order of the purchasing department
response: between 11 and 25

Question 44
concerns the degree of variability of the lead-times of the purchasing department
response: fairly variable

Question 45
concerns your judgement concerning the importance of items with variable lead times of the purchasing department
response: important

Question 46
concerns the percentage of items with variable lead times of the purchasing department
response: 15

Question 47
concerns the status of order size lead time dependencies
response: absent

Question 48
concerns the status of seasonal lead time dependencies
response: absent

Question 49
concerns the status of multi-vendor items
response: present

Question 50
concerns the status of lead-time records in the purchasing department
response: present

Question 51
concerns the purchase cost item of the purchasing department
response: between two and 5 dollars

Question 52
concerns the status of vendor lead time dependencies
response: absent

Question 53
concerns the status of vendor price tradeoffs
response: absent

Question 54
concerns the variable item holding cost of the purchasing department
response: between 20 and 25 percent

Question 55
concerns the status of items with non-instantaneous replenishment rates
response: absent

Question 56
concerns the status of extremely-expensive items
response: not known

Question 57
concerns the status of records of seasonal factors
response: absent

Question 58
concerns the number of the types of seasonal items of the purchasing department
response: more than 5

Question 59
concerns the status of limited-sales-season items
response: present

Question 60
concerns your judgement concerning the importance of limited-sales-season items of the purchasing department
response: important

Question 61
concerns the limited-sales season item overage cost of the purchasing department
response: the cost to liquidate and the off-season holding cost

Question 62
concerns the percentage of limited-sales-season items of the purchasing department
response: 10

Question 63
concerns the status of slow-moving items
response: present

Question 64
concerns your judgement concerning the importance of slow-moving items of the purchasing department

response: important

Question 65
concerns the percentage of slow-moving items of the purchasing department
response: not known

Question 66
concerns the status of items with erratic demand
response: absent

Question 67
concerns the status of fashionable items
response: absent

Question 68
concerns the status of promoted items
response: not known

Question 69
concerns the status of advertised items
response: not known

Question 70
concerns your judgement concerning the importance of support of prediction item-life
response: unimportant

Question 71
concerns the status of items that experience large orders
response: present

Question 72
concerns your judgement concerning the importance of control of items that experience large orders of the purchasing department
response: unimportant

Question 73
concerns the status of emergency lead-times
response: present

Question 74
concerns your judgement concerning the appropriateness of the safety lead-times of the purchasing department
response: appropriate

Question 75
concerns the status of emergency lead-time quantity-restrictions
response: present

Question 76
concerns the status of emergency lead-time price-increases
response: present

The following is a list of possible summaries of responses to questions.

Please select one of the following:

1 print a summary of all questions
2 print selected questions
3 return to toplevel

(Enter here): 1

Mr. Smith feels that he has done enough for today. (The session took about an hour of terminal interaction.) He saves his session and goes home.

And Mr. Smith, you are at top level. Please select one of the following:

1 quit
2 continue the analysis
3 help
4 change answers
5 summarize the analysis

(Enter here): 1

Now do you really want to quit?
(Please key in yes or no): y

Do you wish to save what you have done so far?
(Please key in yes or no): y

A record of this session will be saved. Mr. Smith, do want a listing of the session submitted for printing?
(Please key in yes or no): n

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: Technical Report 160	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)*: A Program for the Design of Procurement Systems	5. TYPE OF REPORT & PERIOD COVERED: S.M. Thesis, May 7,1976
6. PERFORMING ORG. REPORT NUMBER: Technical Report 160	
7. AUTHOR(s): Michael Bosyj	8. CONTRACT OR GRANT NUMBER(s): N00014-75-C-0661
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Massachusetts Institute of Technology Laboratory for Computer Science 545 Technology Square Cambridge, Massachusetts 02139	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Advanced Research Projects Agency Department of Defense 1400 Wilson Boulevard Arlington, Virginia 22209	12. REPORT DATE: May 1976 13. NUMBER OF PAGES: 169
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: Office of Naval Research Department of the Navy Information Systems Program Arlington, Virginia 22217	15. SECURITY CLASS. *(of this report)*: Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Interactive Questionnaires
Applications Customizers
Hierarchical Planning and Control Systems for Procurement
Knowledge-based Systems

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Computer technology has had limited success in producing useful business applications. Management systems seldom meet users' requirements, are often inappropriate to an application, and are frequently abandoned. But why?

Business lacks expertise in the application of computers. Managers who are expert in solving business (cont'd)

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20. problems find it difficult to specify formal procedures for the solution of these problems. It is not surprising that programmers who work from poorly defined specifications produce poorly written software. The computer industry has provided only limited support in business applications. Application packages are seldom appropriate to a problem and are often misapplied. Misapplication is the principle reason for their failure in practical situations.

Improvements are certainly possible. The manager could be supplied with a system that assists in the design of an application. This system could help the manager specify his requirements by providing him with a framework for thinking about issues relevant to the design of a particular application. The manager might then be better equipped to select a commercial package or to guide in the design of his own implementation.

This thesis describes a prototype version of such a system. PROCTOR is a program that assists in the design of a hierarchical planning and control system for a procurement firm.

PROCTOR is implemented as an "unstructured" questionnaire. It guides the user in investigating various aspects of a problem while giving him complete freedom in deciding how and when to supply answers to questions. It allows him to change and skip answers whenever he desires. PROCTOR is implemented in OWL, a system for representing and processing conceptual knowledge. It uses the OWL data base to represent procedures for the questionnaire and to store data accumulated during the interaction. This representation makes possible the presentation of an English-like problem description, various evaluations and the reasons for the evaluations.

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